

The NASA K2 Mission

Tom Barclay

K2 Guest Observer Office Director
NASA Ames Research Center

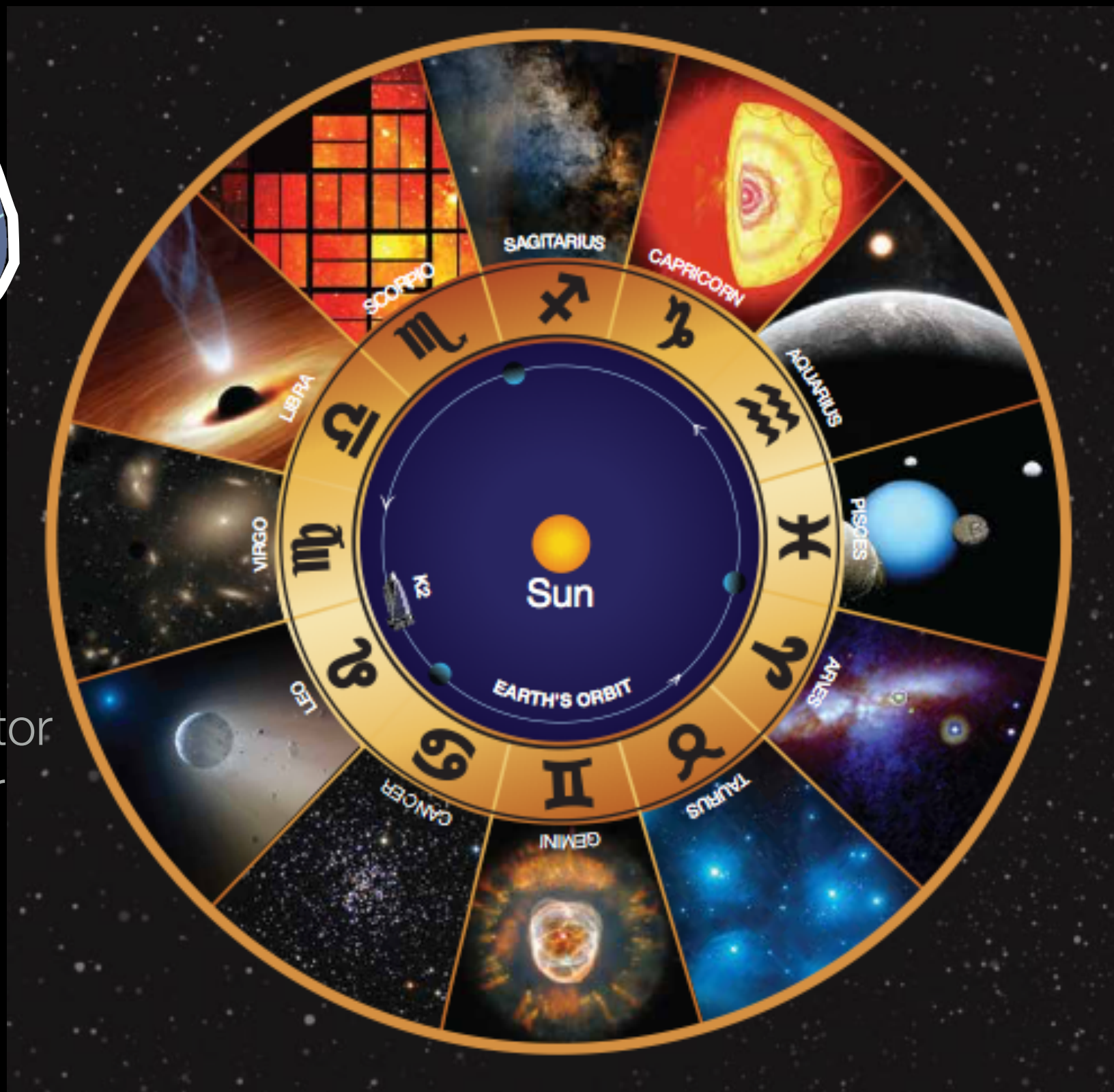
K2 Splinter Session
Jan 5, 2016

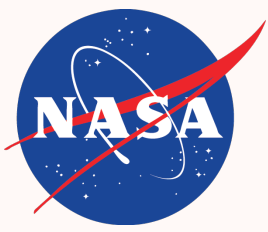


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ExoPAG 14, San Diego
June 12, 2016





K2 Special Session

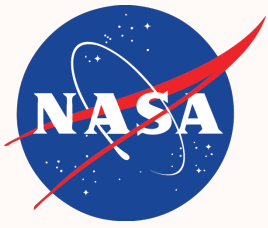


Monday, June 13. 10.00am

Room: Indigo A (second floor)

Talks on K2 status, exoplanets, supernovae, microlensing,
Spitzer/JWST synergy, ultra-cool dwarfs and clusters





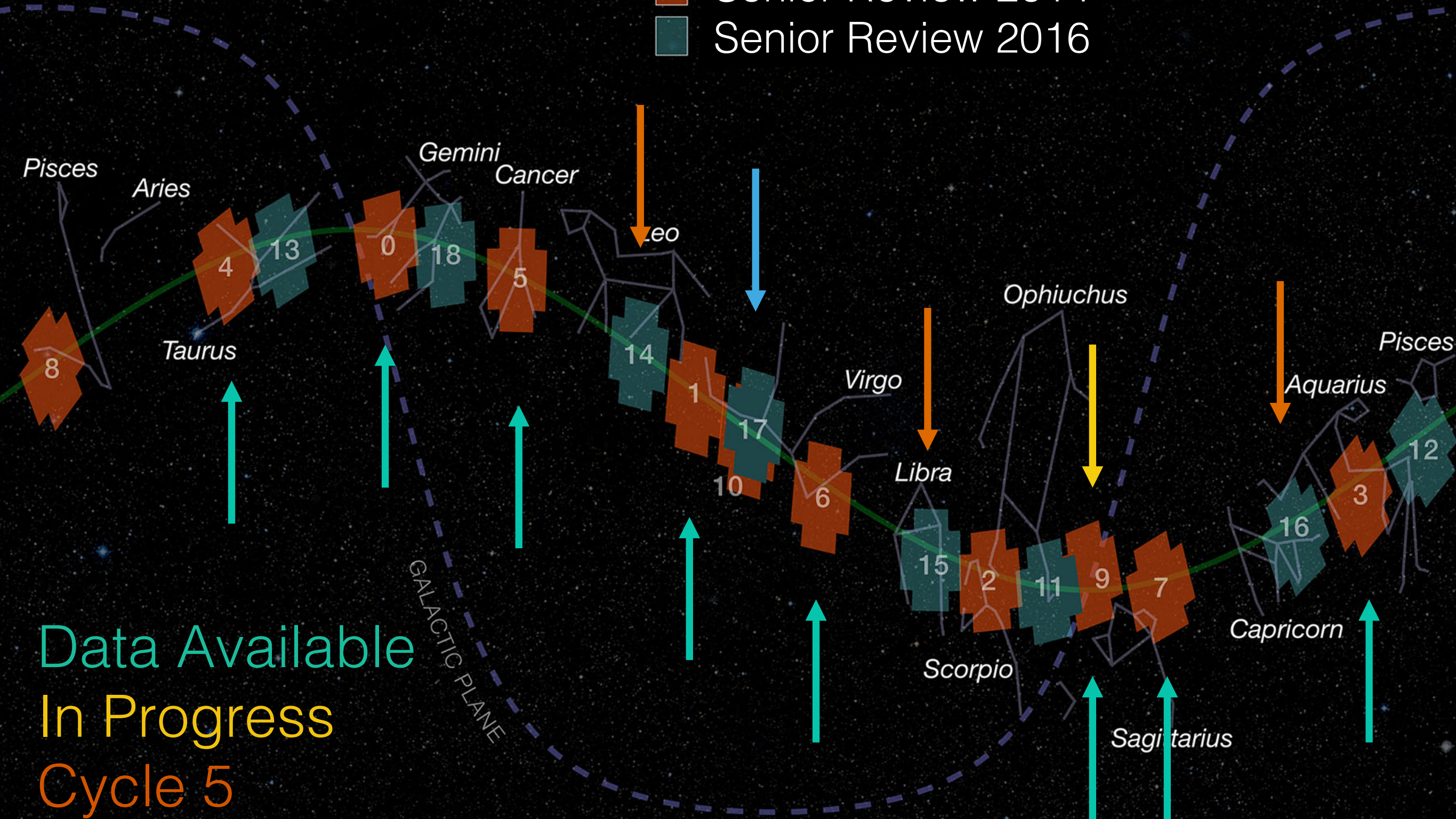
Takeaways

The K2 mission will continue until the end of the spacecraft lifetime

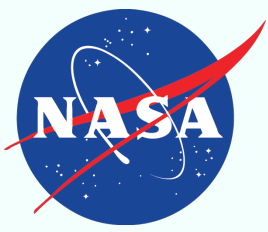
Many earth and super-earth-sized planets have been detected orbiting nearby cool stars

The K2 Microlensing Experiment serves as a pathfinder for microlensing with WFIRST

Senior Review 2014
 Senior Review 2016



Data Available
 In Progress
 Cycle 5
 Supernova-focused



K2 Senior Review Results



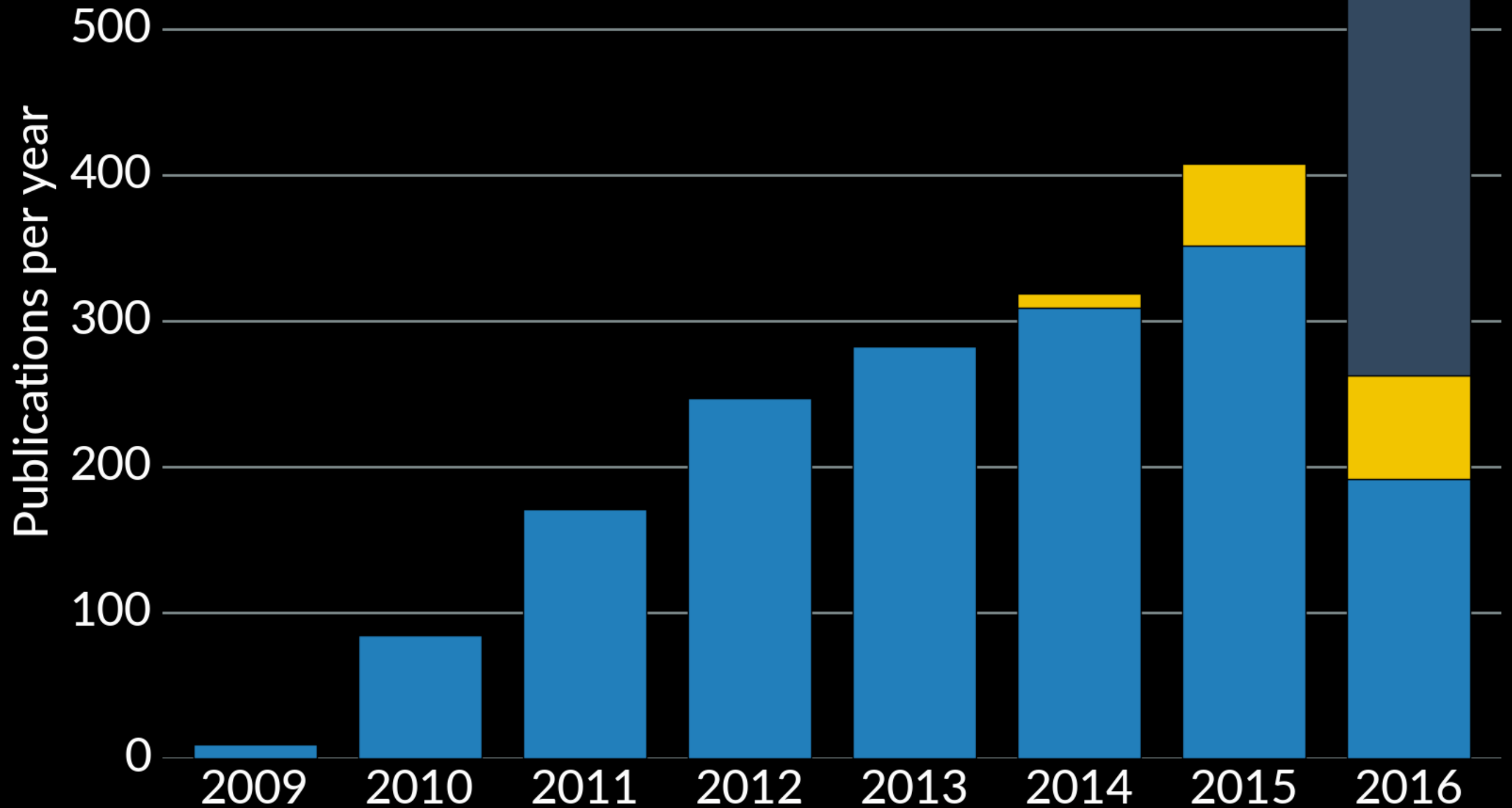
- K2 ranked Excellent in all three categories
 - synergies between K2 and Spitzer were emphasized
- Funding recommended in FY 17/18/19
 - through end of the operating lifetime (~mid-2018)
- *"...with a very efficient GO program, the project includes worldwide participation covering every continent except Antarctica. The GO program is recognized the wealth of new scientific results."*

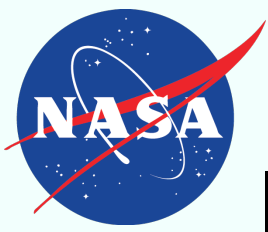
K2-south?



Kepler/K2 Contributed to 1786 Publications So Far

■ Kepler ■ K2 ■ Extrapolation

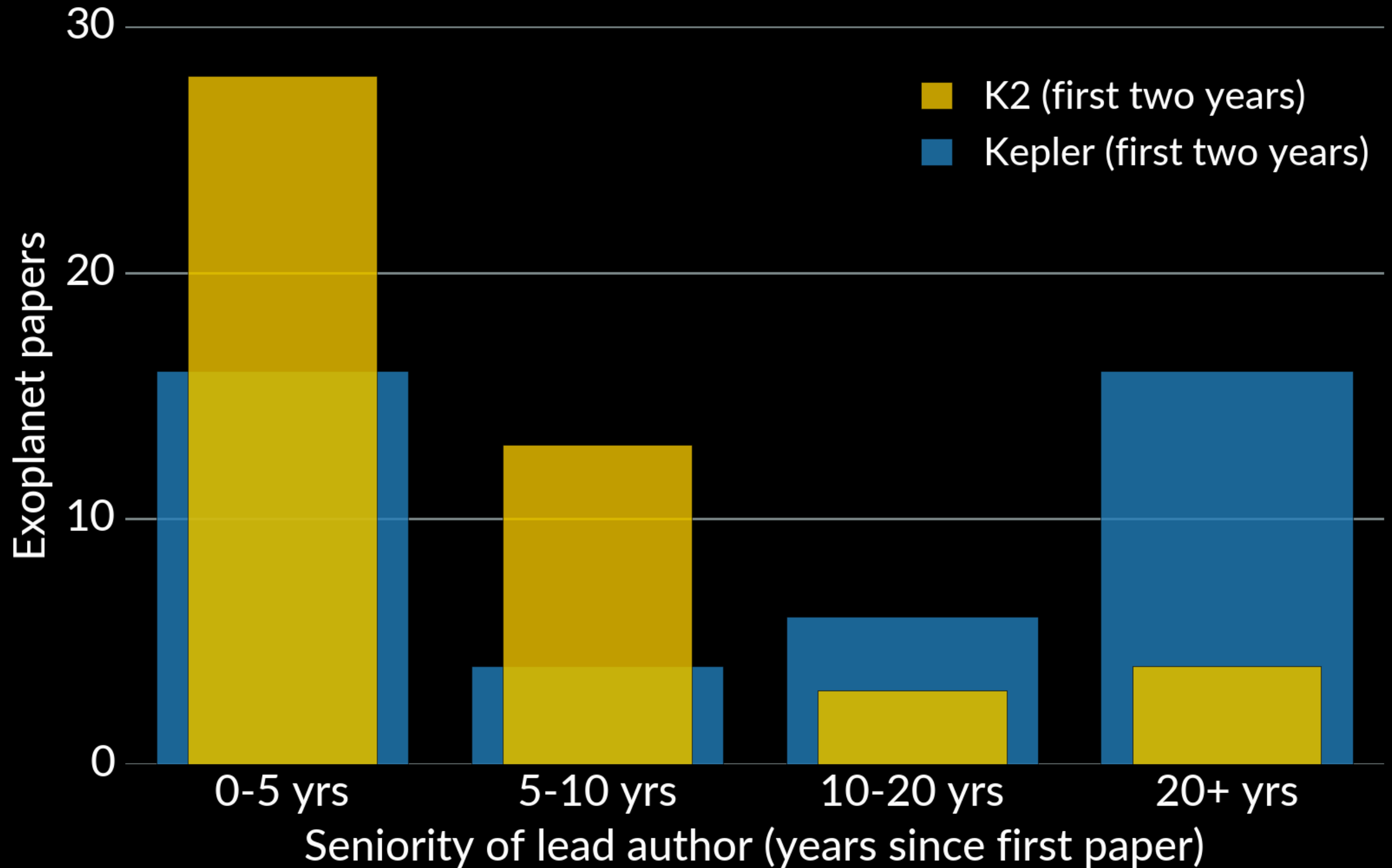


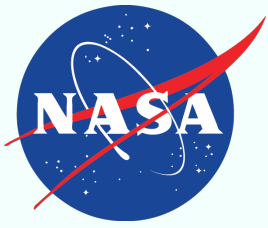


Incentivizing Publication and Innovation

- No proprietary data enables *all* those with skills and talent to benefit from the data collected
- Funding of competing groups to do the *same* science
- Requiring large programs to provide products of value to the community
- We are experimenting with release of science data as soon as it's on the ground
- K2 can inform policies for future missions
 - potential to contrast with Kepler

K2's Open Data Policy Empowers Early-Career Astronomers



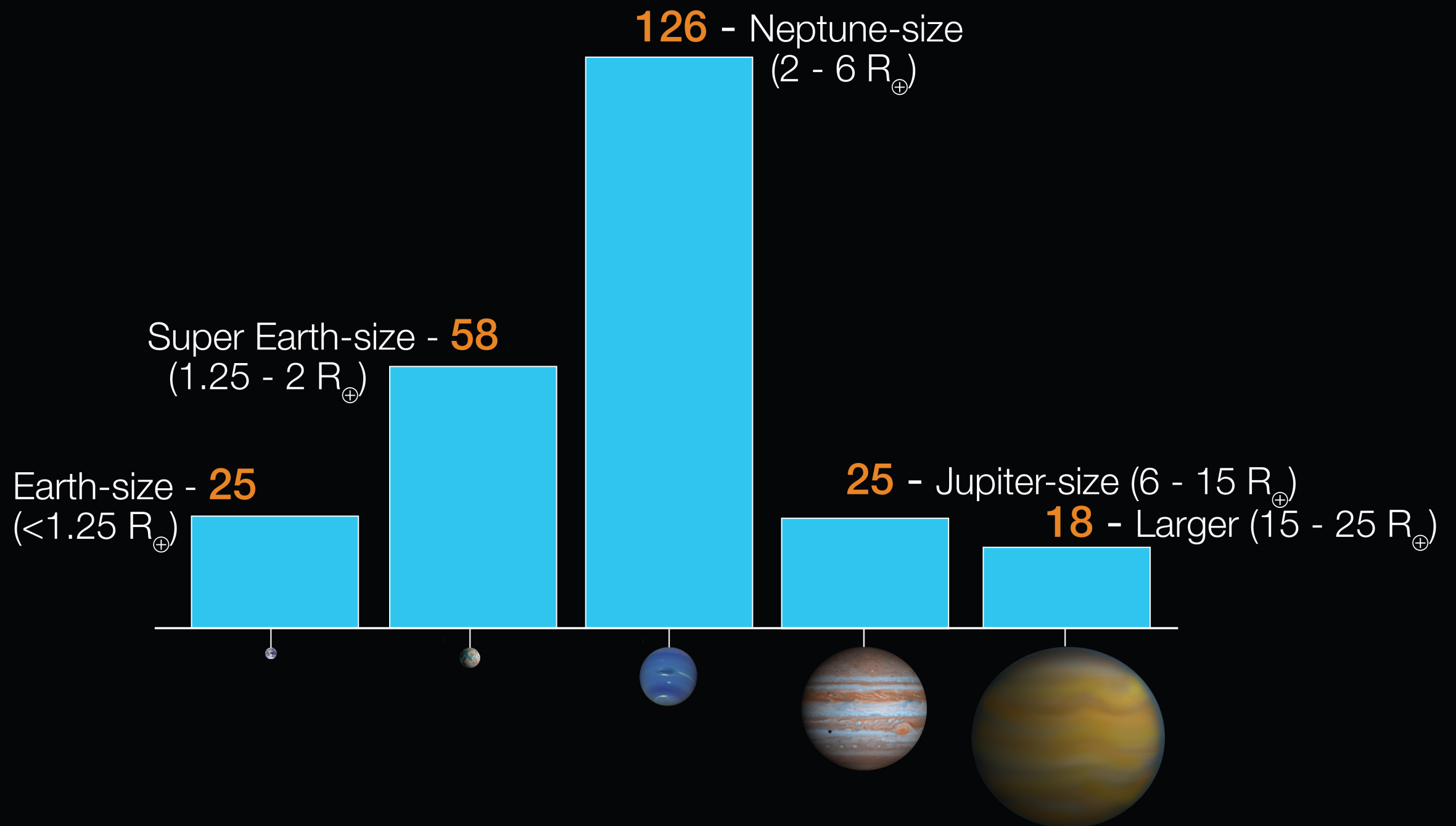


Future Opportunities with K2



Sizes of K2 Planet Candidates

As of June 1, 2016

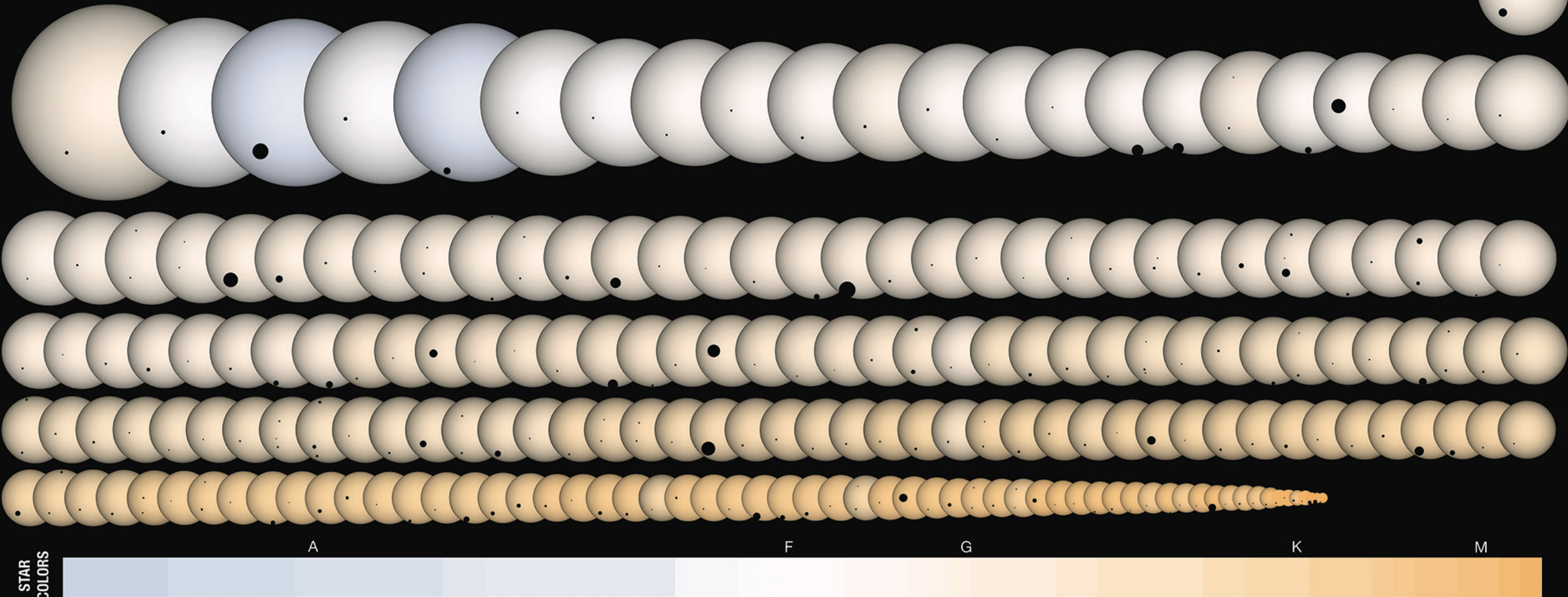




K2'S PLANET CANDIDATES

252 as of June 2016

Jupiter transiting the Sun →

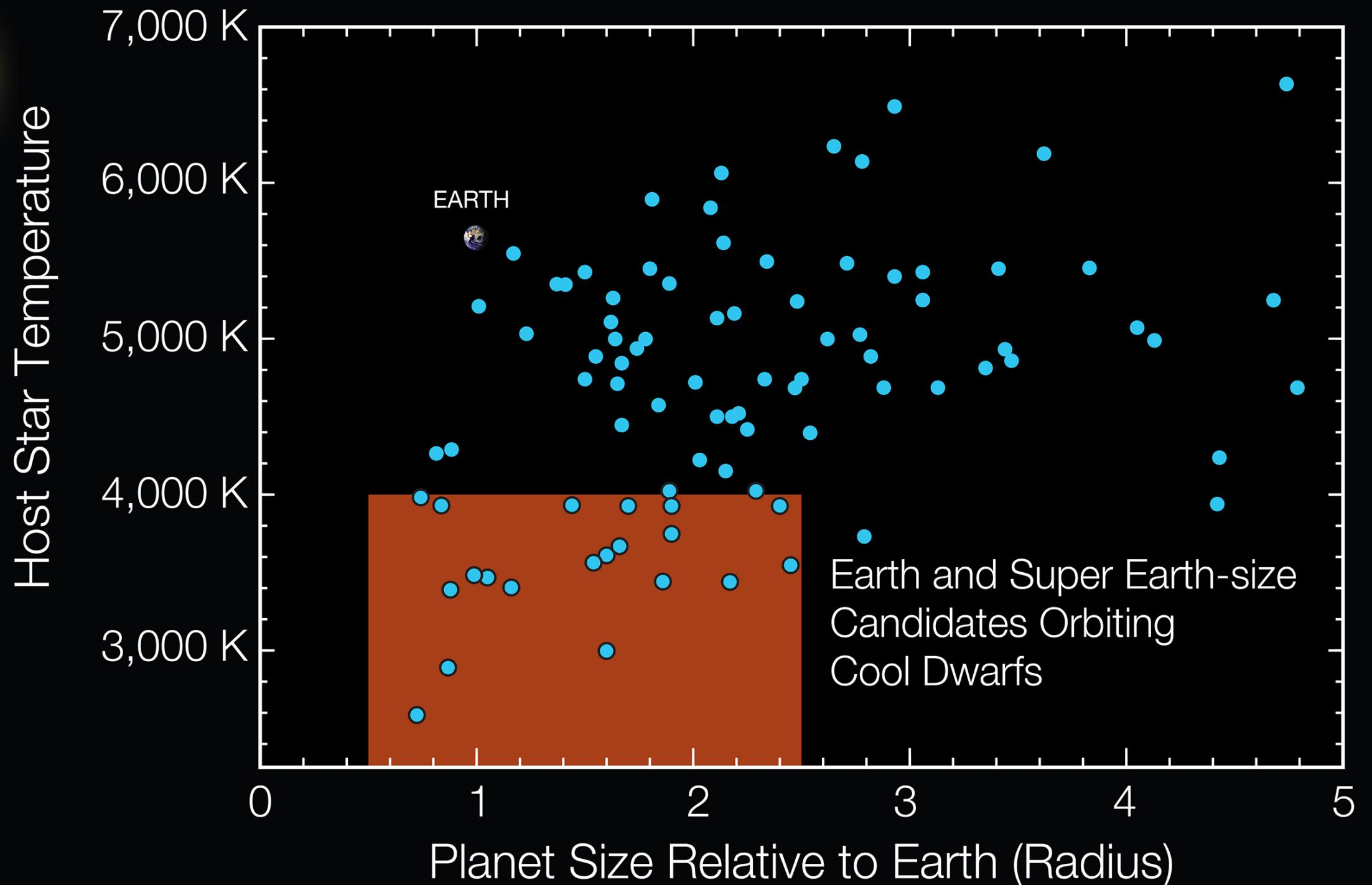


NASA's K2 mission has discovered 252 planet candidates orbiting other suns since beginning full operations in June 2014. The K2 mission uses the the Kepler space telescope to conduct a series of sequential observing campaigns of fields distributed around the ecliptic. In these campaigns, K2 finds planets that transit their star, which means that there is a slight dimming of starlight when the planet crosses the face of its star. In this diagram, the planetary systems are ordered by decreasing

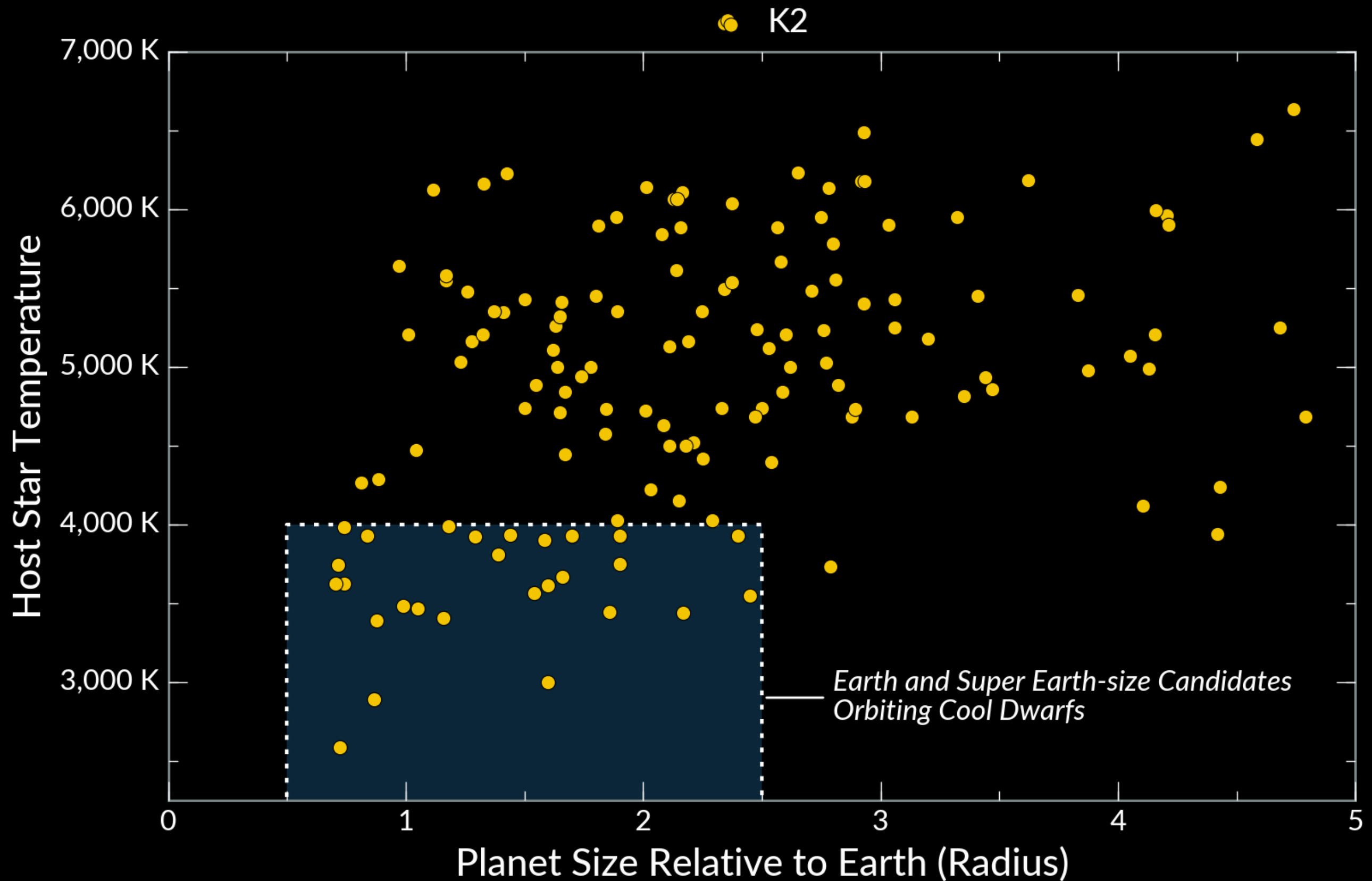
diameter of the host star. The star's color represents its temperature as shown in the lower scale, and the letters (A, F, G, K, M) designate star types. The simulated stellar disks and the planet silhouettes are shown on the same scale as that of our Sun and Jupiter shown in the upper right. Look carefully: some systems have multiple planets. New exoplanets are discovered every few months as more data is collected and analyzed. A higher resolution version of this graphic is available at: http://www.nasa.gov/mission_pages/kepler/multimedia.

NASA's K2 Planet Candidates for Atmospheric Characterization ($K_s < 11$)

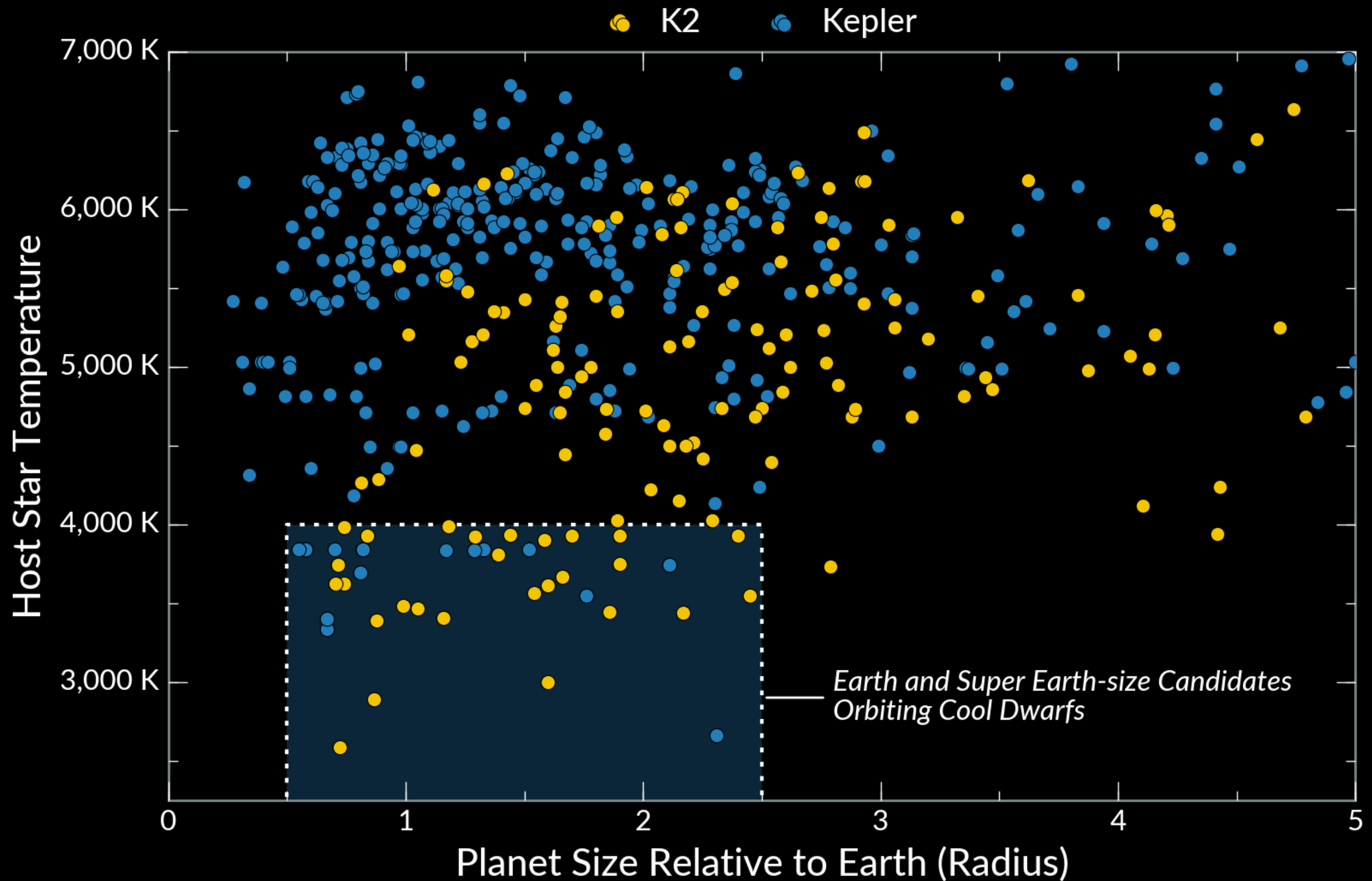
As of June 1, 2016

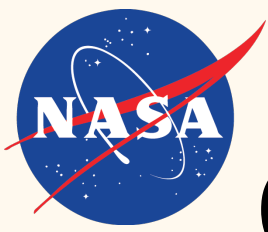


Planet Candidates for Atmospheric Characterization ($K_s < 11$)

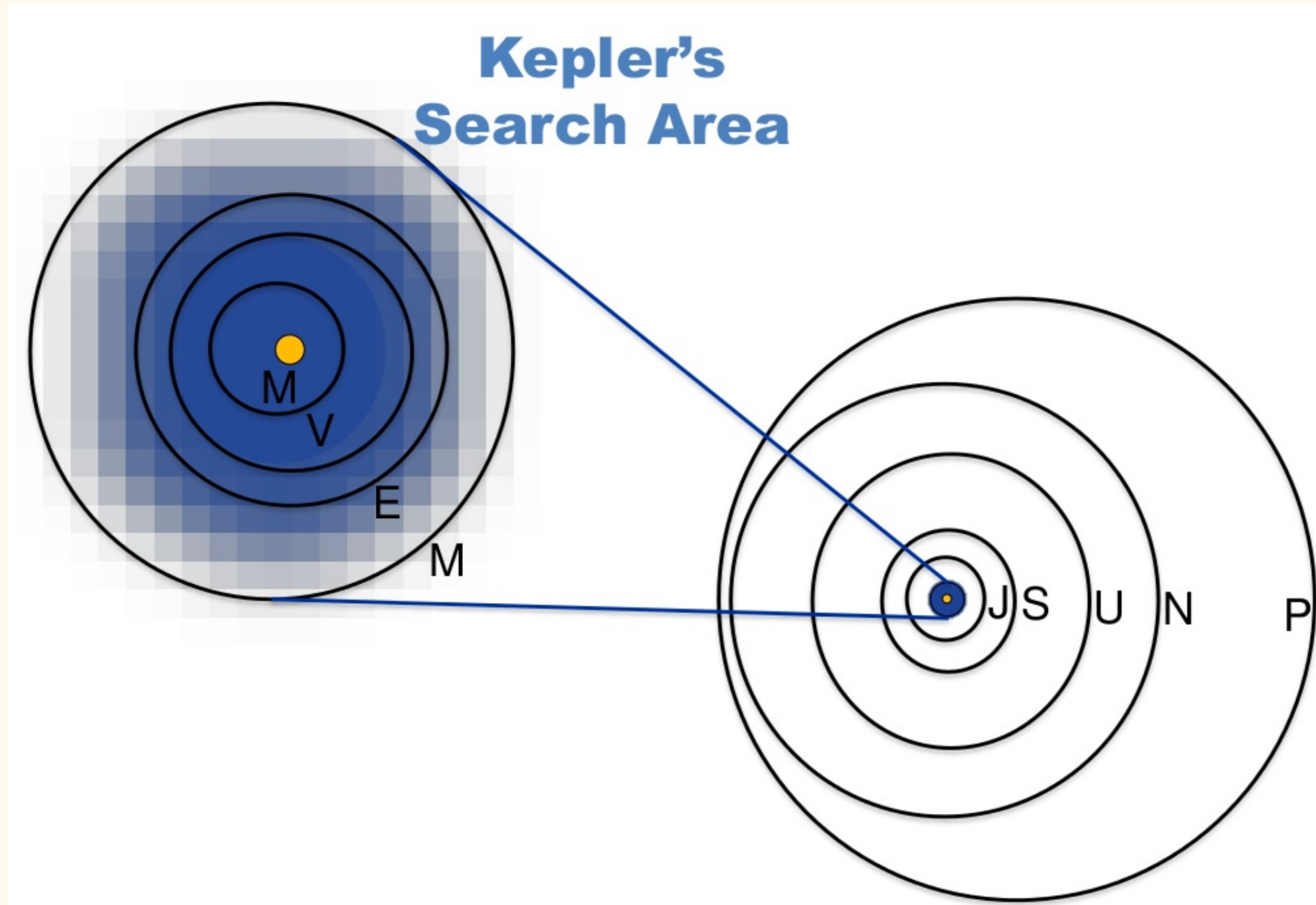


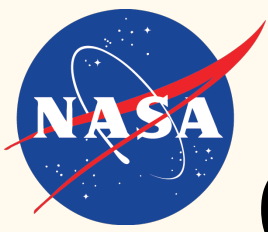
Planet Candidates for Atmospheric Characterization ($K_s < 11$)



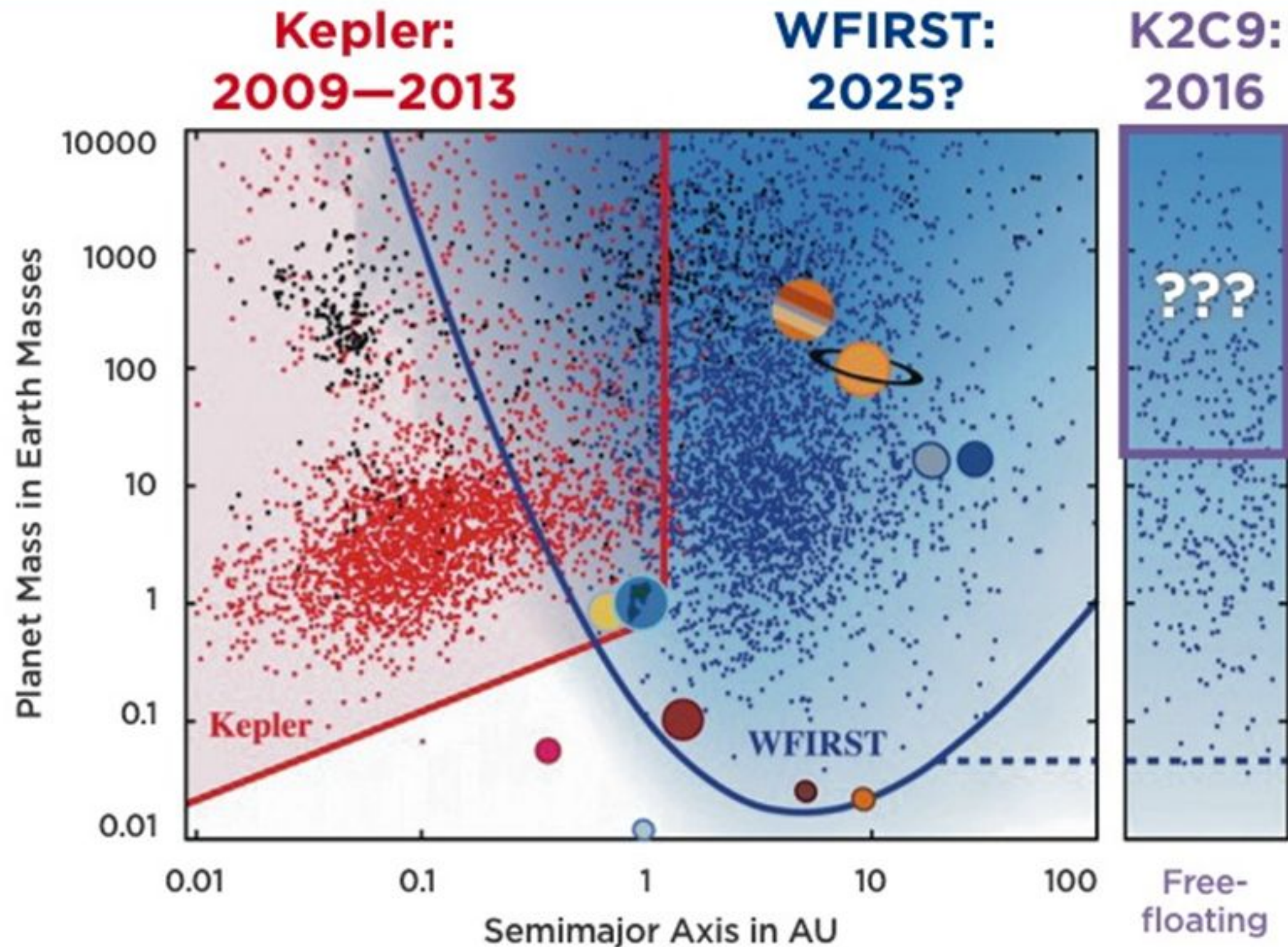


Completing the Exoplanet Census

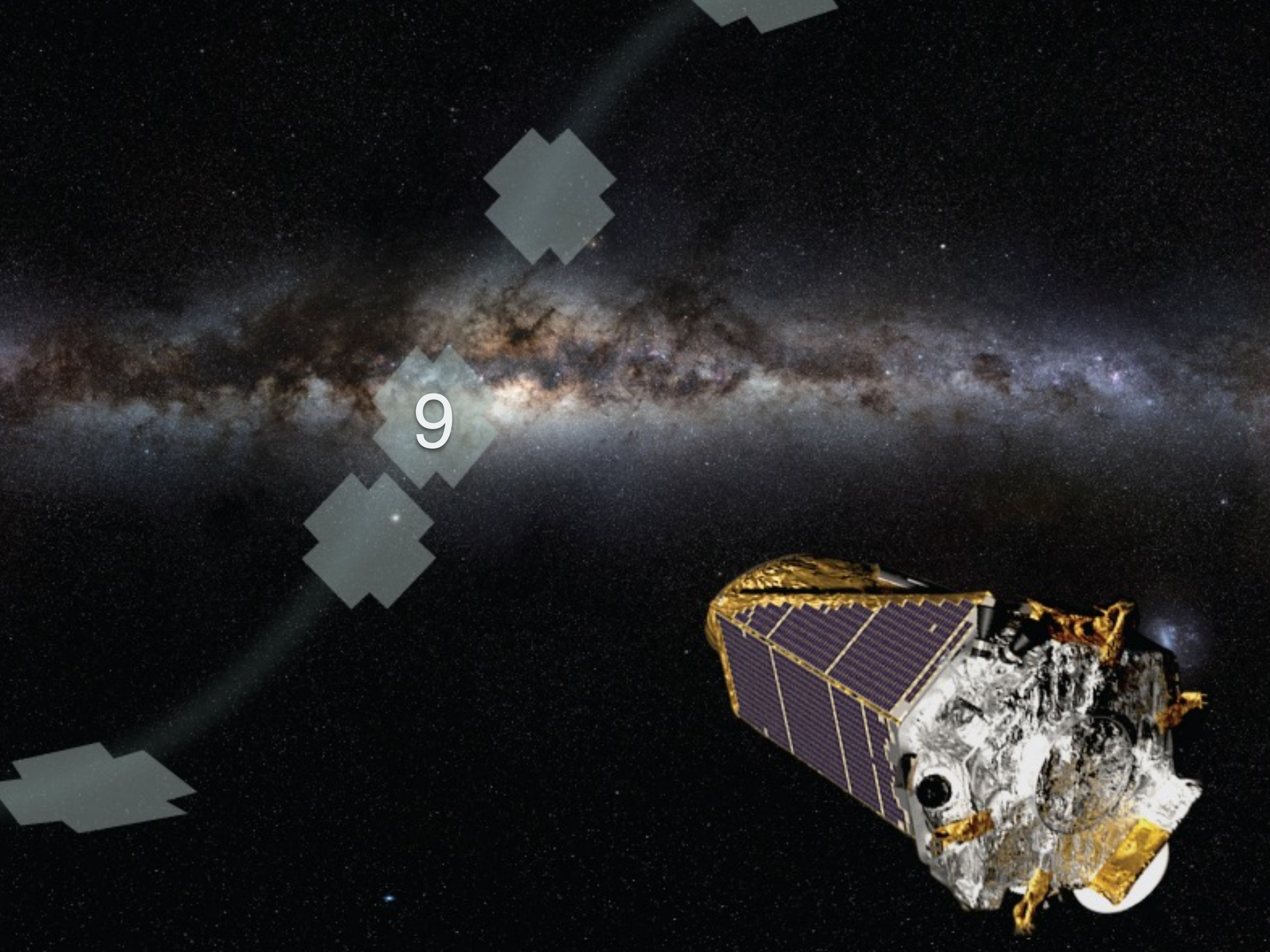




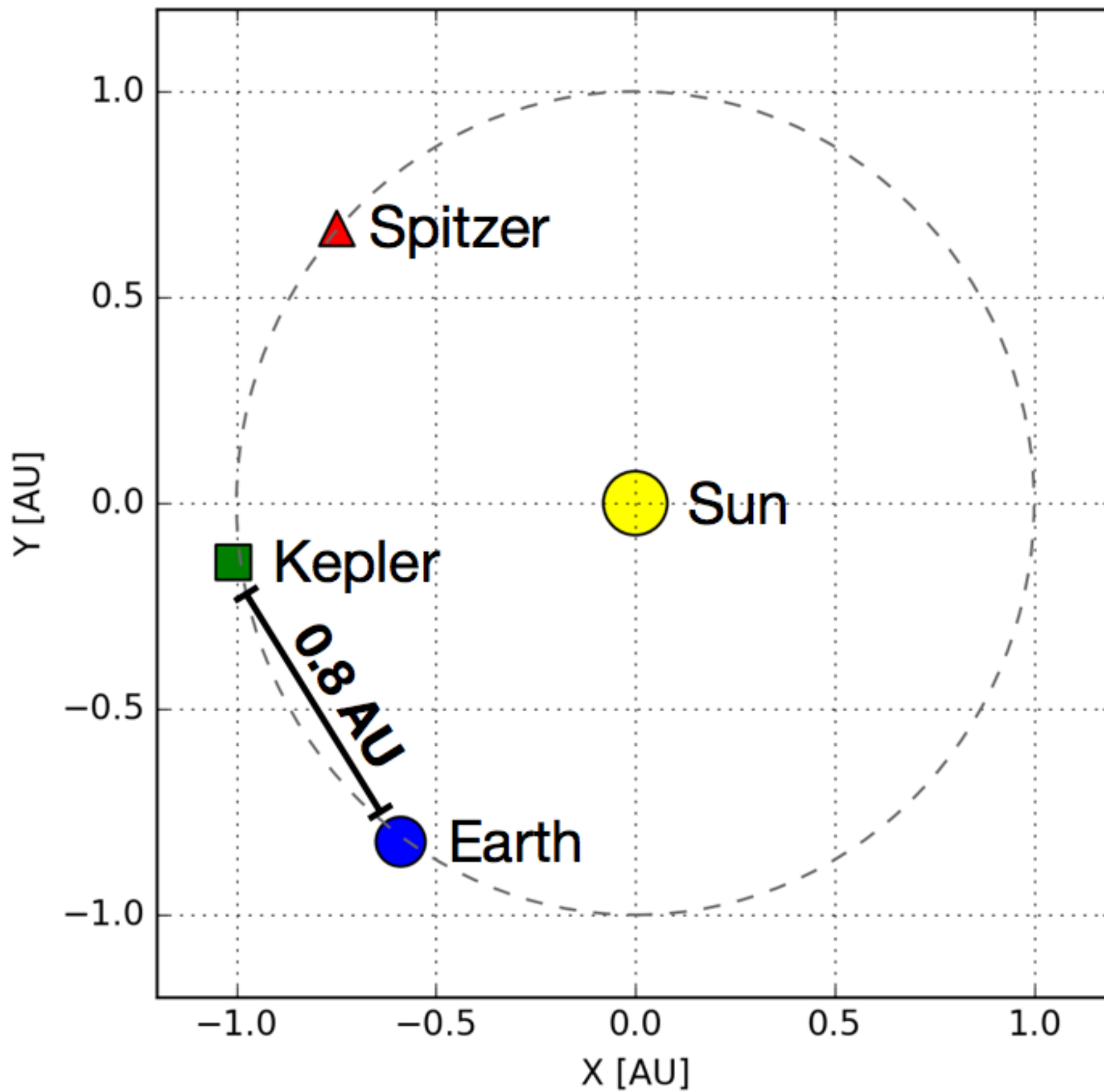
Completing the Exoplanet Census



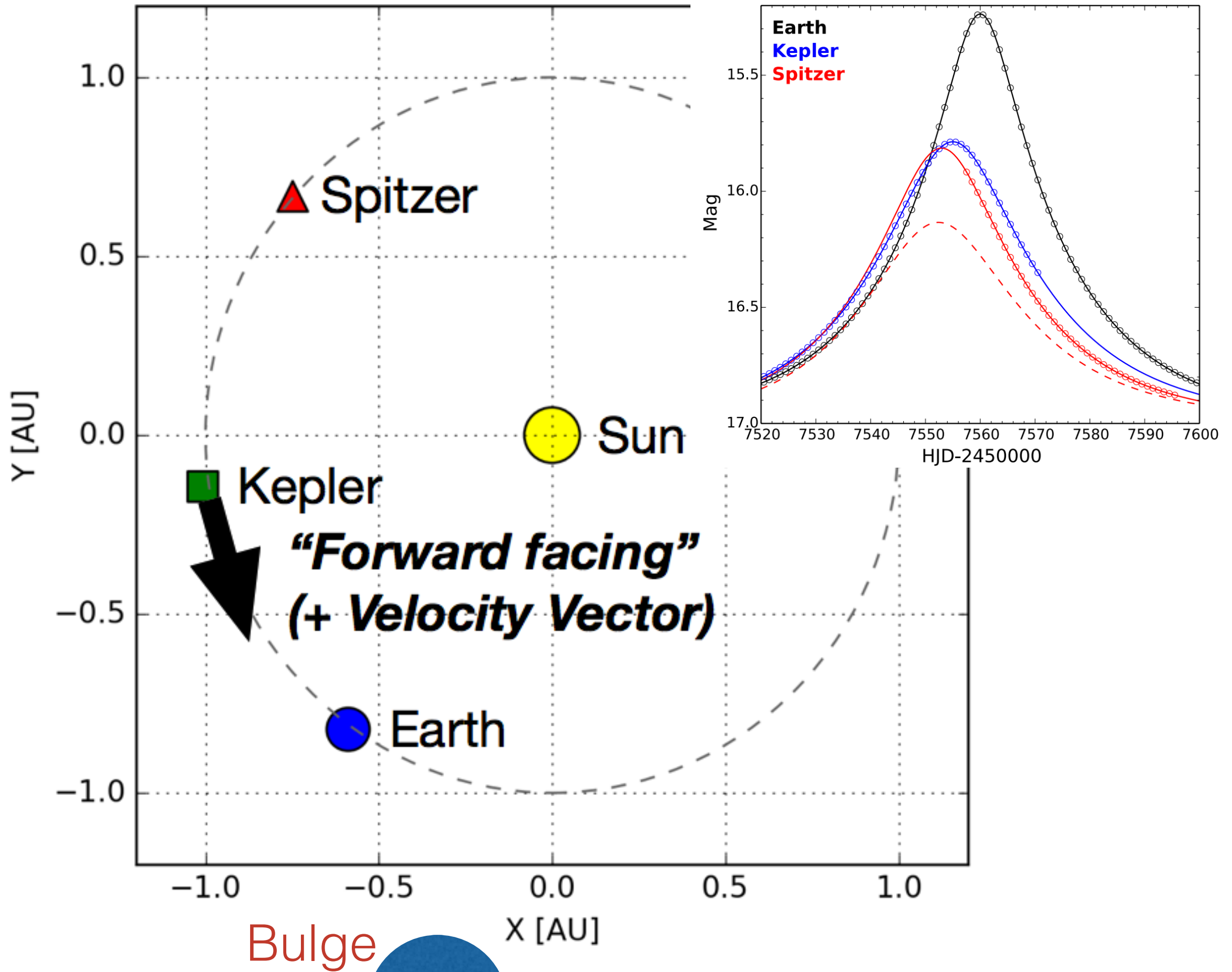
Using Starlight to Find Wandering Worlds

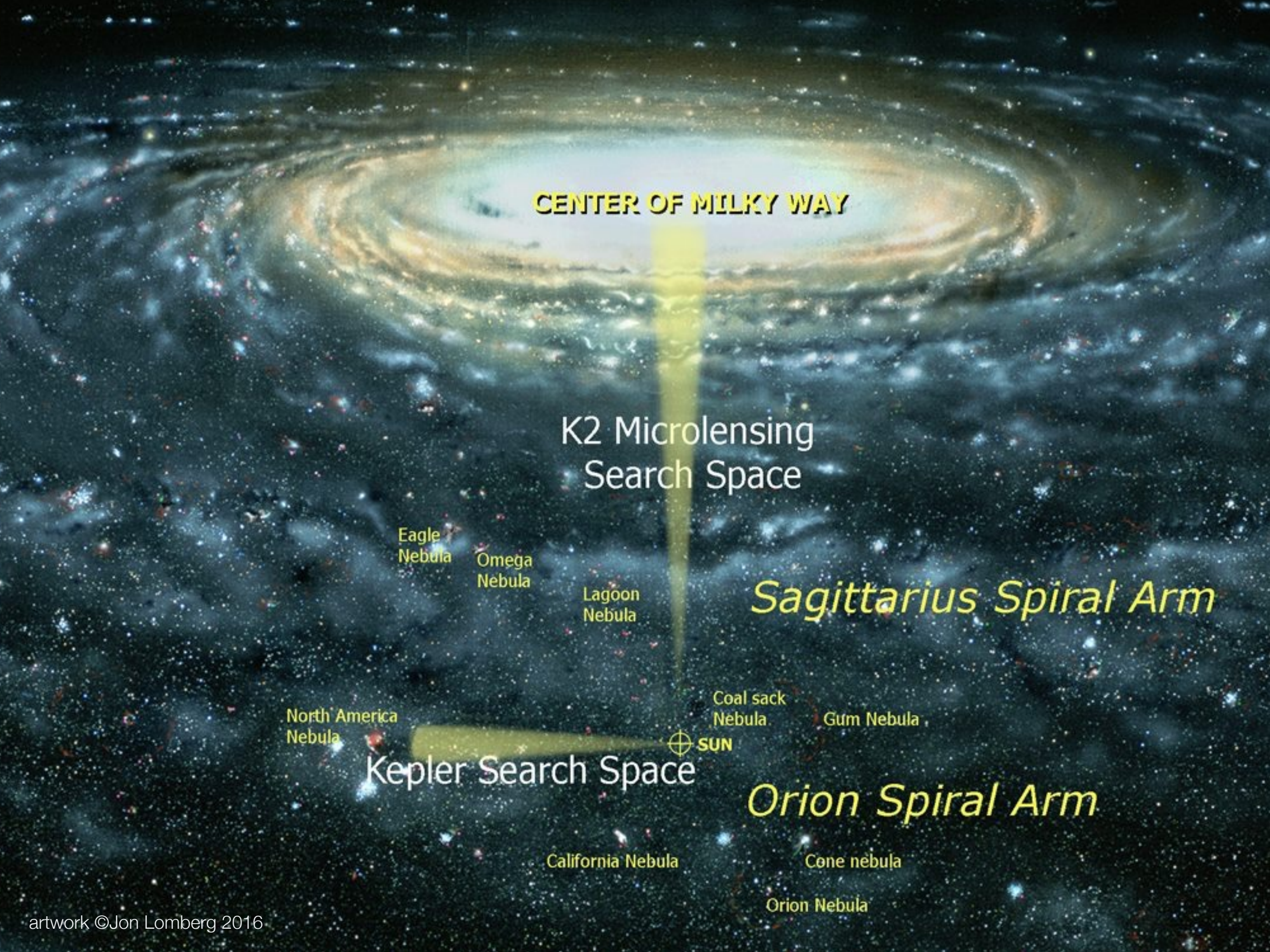


View from above on 15 May 2016



View from above on 15 May 2016





CENTER OF MILKY WAY

K2 Microlensing
Search Space

Eagle
Nebula

Omega
Nebula

Lagoon
Nebula

Sagittarius Spiral Arm

North America
Nebula

Coal sack
Nebula

Gum Nebula

SUN

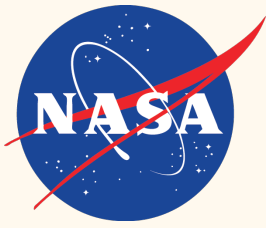
Kepler Search Space

Orion Spiral Arm

California Nebula

Cone nebula

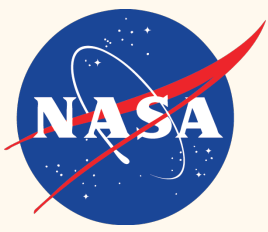
Orion Nebula



Microensing Science Team



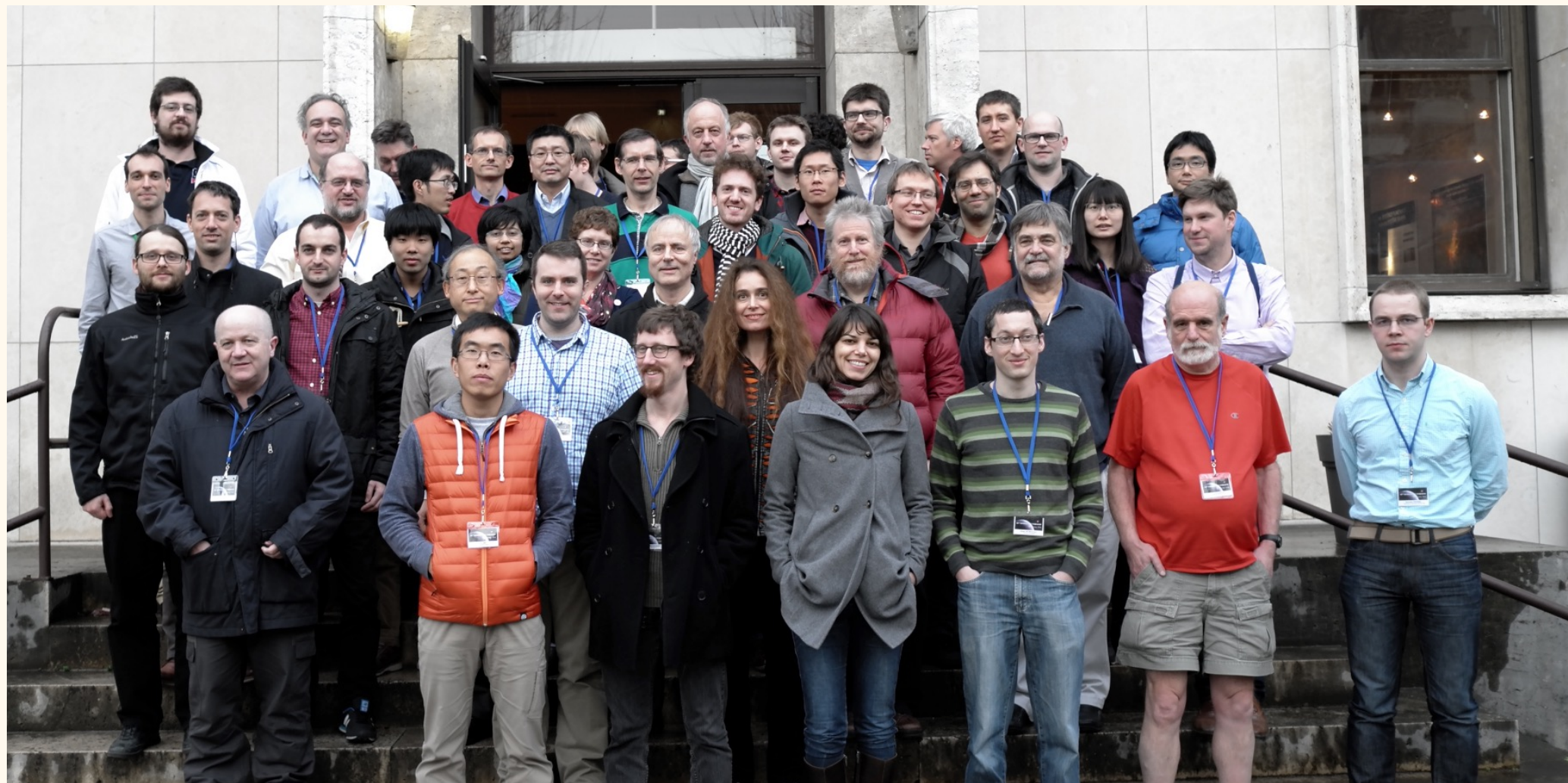
- We recognized the need for a single, cohesive unit with a charge to represent and serve the best interests of the microensing scientific community
- Two essential tasks
 - Facilitating simultaneous ground-based data collection and analyses of those ground-based data
 - Development and execution of methods that ensure accurate, under-sampled, crowded field photometry
- We aimed to provide an environment that enabled new talent to get involved with microensing

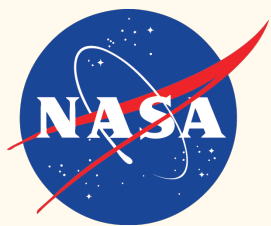


Microlensing Science Team

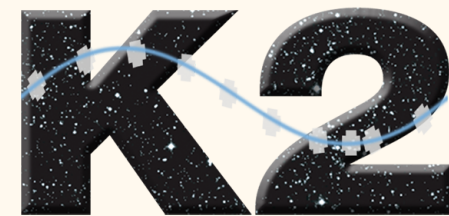


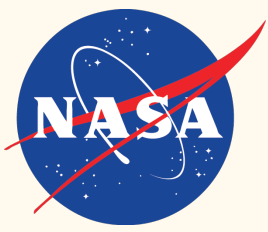
- Achievements so far include
 - Wrote a white paper (arXiv: 1512.09142)
 - Set up an open mailing list and wiki
 - Secured telescope resources during C9 on every continent (except Antarctica!)
 - With NExSci, developed real-time events database and telescope calendar
 - Selected targets and pixels for downlink
 - Started identifying and analyzing events using newly developed photometry techniques





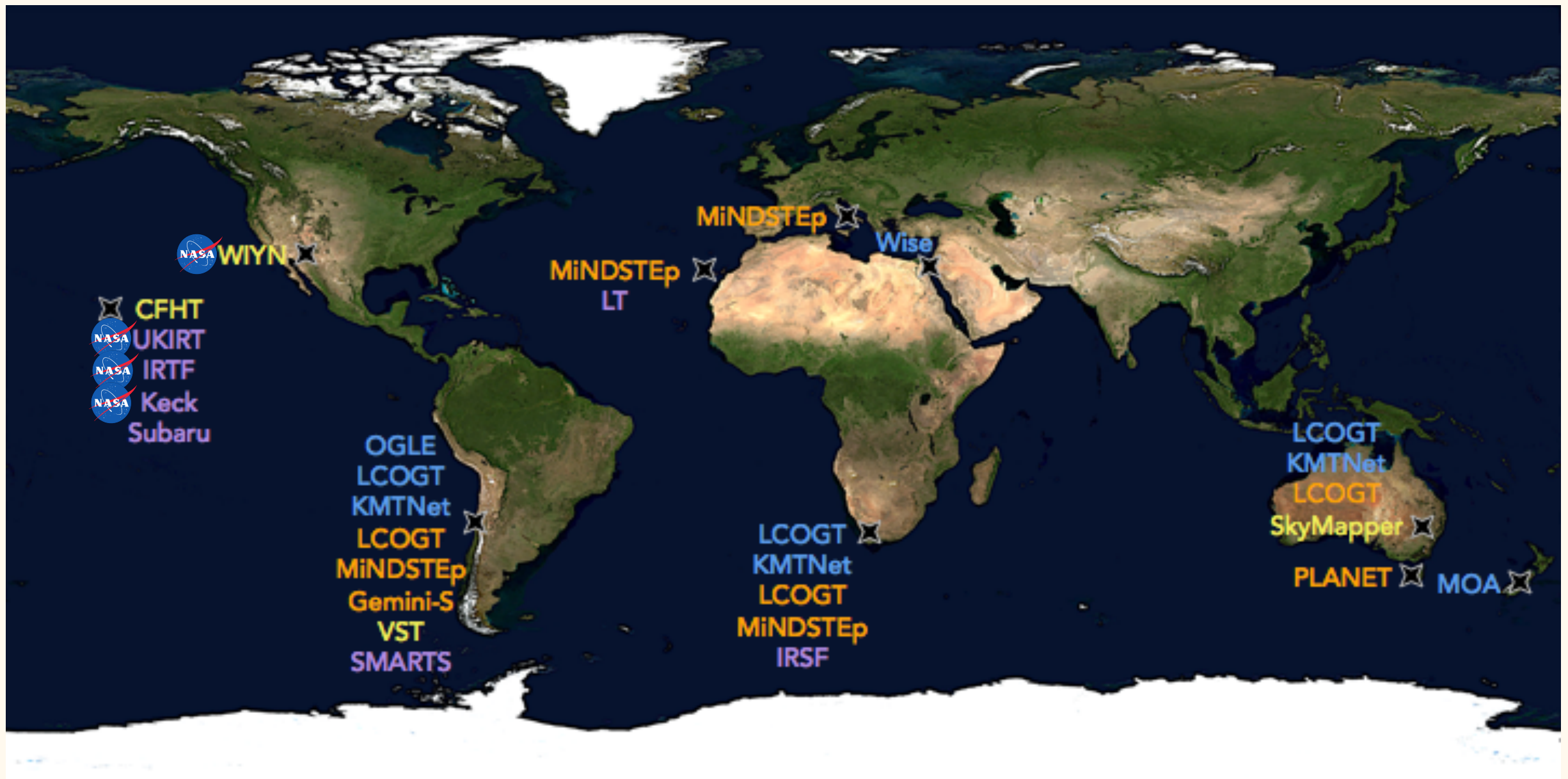
Microlensing Science Team

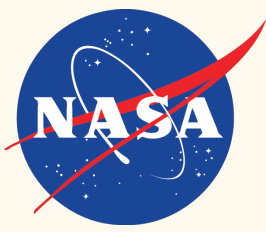




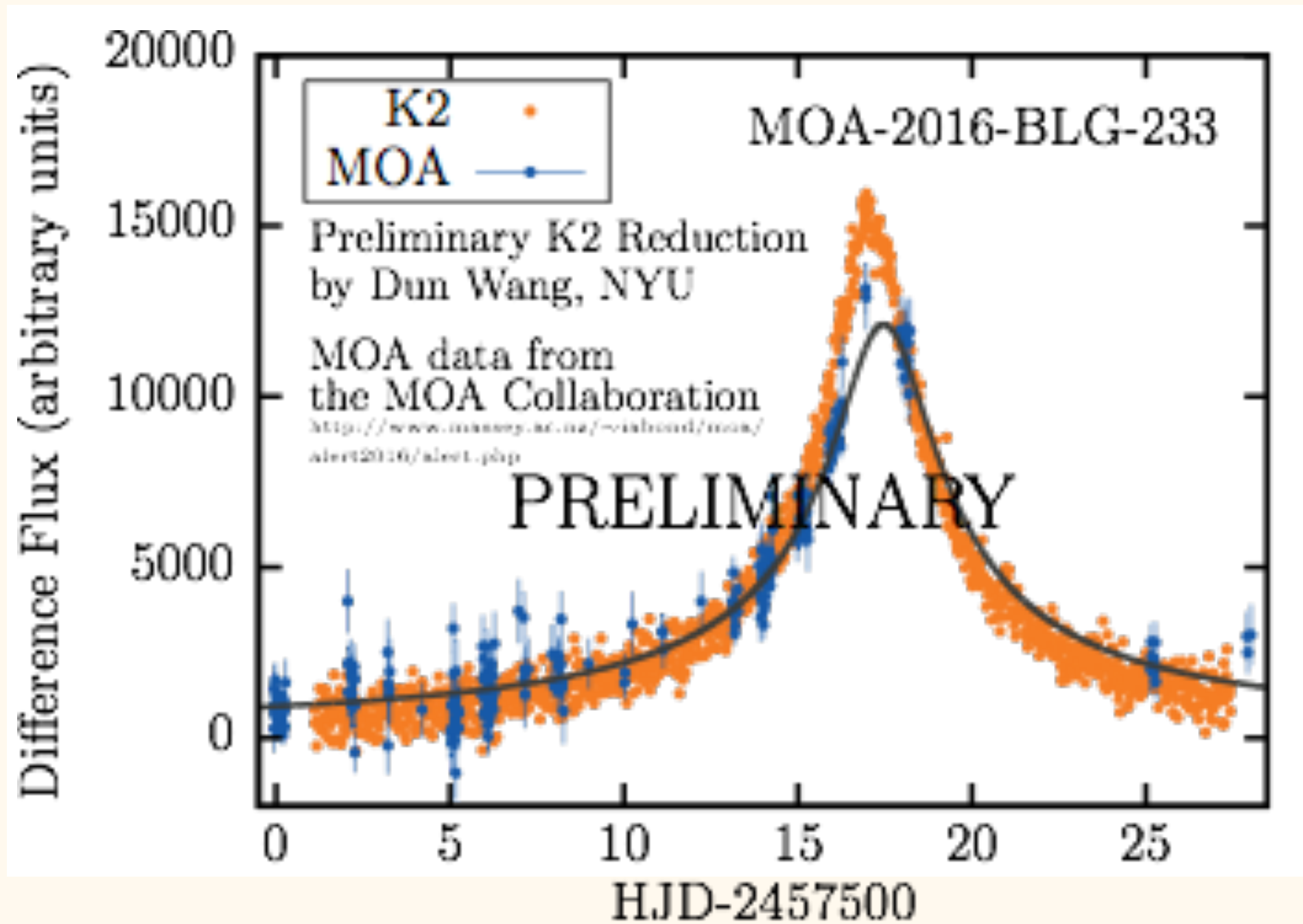
K2 Microlensing Experiment

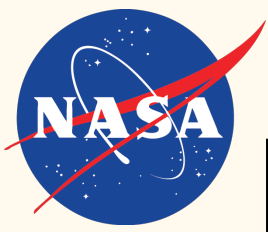
Obtaining sufficient telescope resources was a key component to a successful campaign and our #1 risk





Early Demonstration

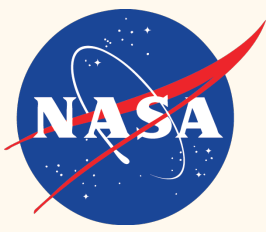




Role as a Pathfinder



- Flexibility from the K2 team at NASA and Ball enabled a brand new science experiment using existing capabilities
 - Changing the spacecraft pointing direction
 - Reducing the target selection lead time to a few weeks
 - Instant access to the raw data, enabling rapid follow-up
- The unique capabilities offered by a space mission can unite and grow a community



Role as a Pathfinder



- A pathfinder for future missions
 - For WFIRST: K2 C9 is growing expertise within the current microlensing community, and also growing that community with additional skills and talent
 - C9 is showing that the community is able to extract high-value, time-sensitive information from raw spacecraft data with minimal mission support
 - we wrote one 600-line software package to parse the data
 - to enable time-critical science, should providing instant access to data become the default for future missions?



KEPLER & K2 SciConIV: Legacy & Scion

2017 JUNE 19-23
NASA Ames
Research Center
Moffett Field, CA

NASA'S KEPLER/K2 MISSIONS

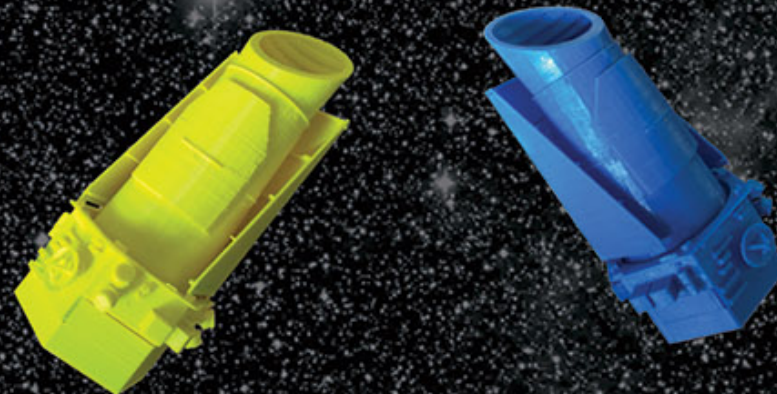
KEPLER MODEL GIVEAWAY!!

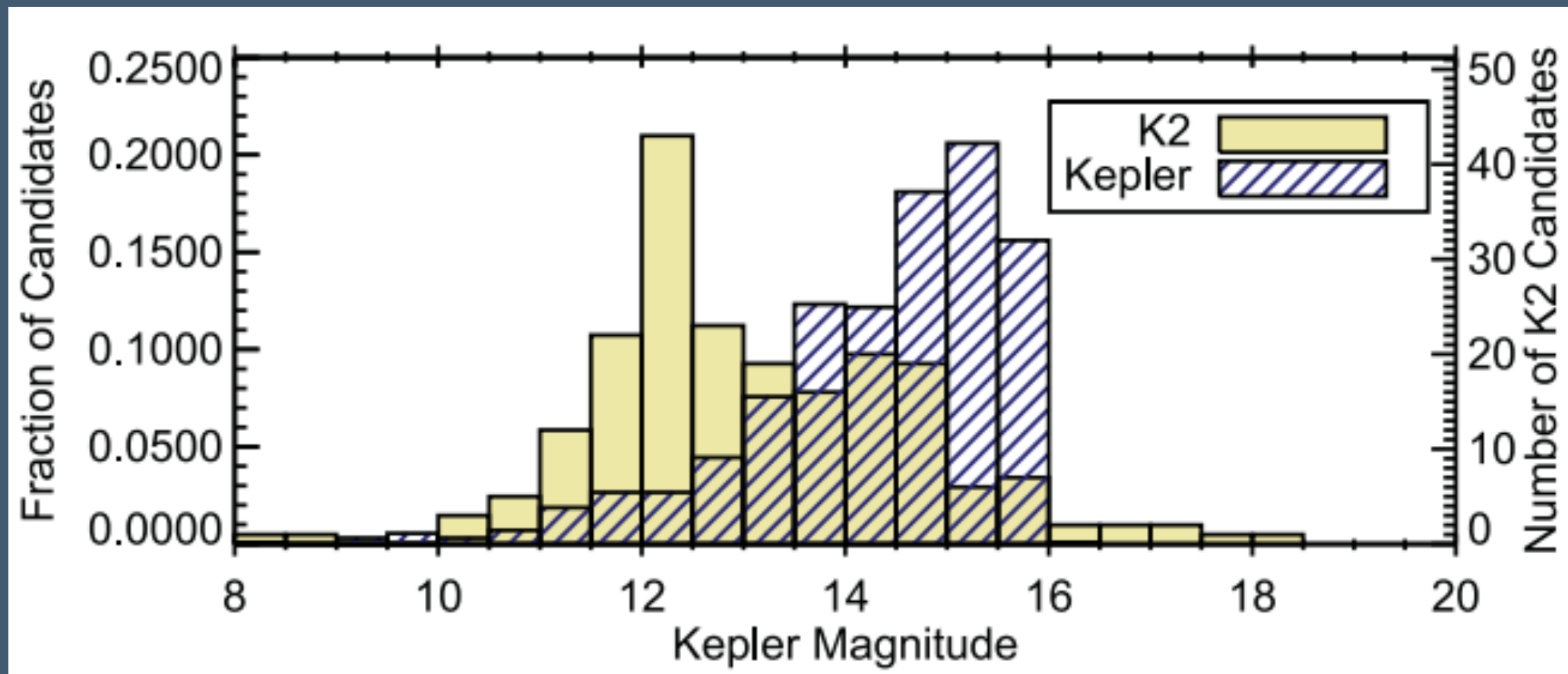
Win a 3d-printed KEPLER!!

(1/33 scale)

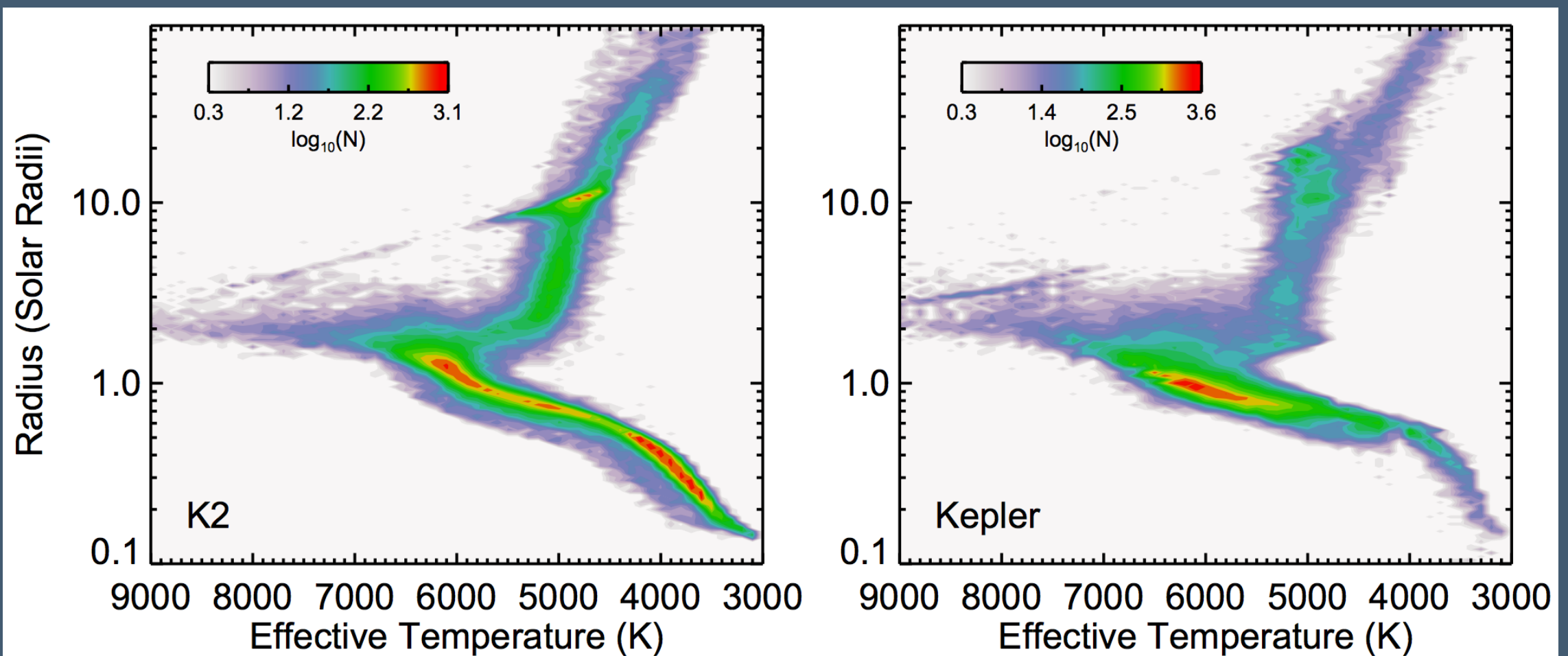
**DRAWING AT 6:00 PM
WEDNESDAY, JUNE 15
AT THE KEPLER/K2 BOOTH (#106)**

YOU MUST BE PRESENT TO WIN



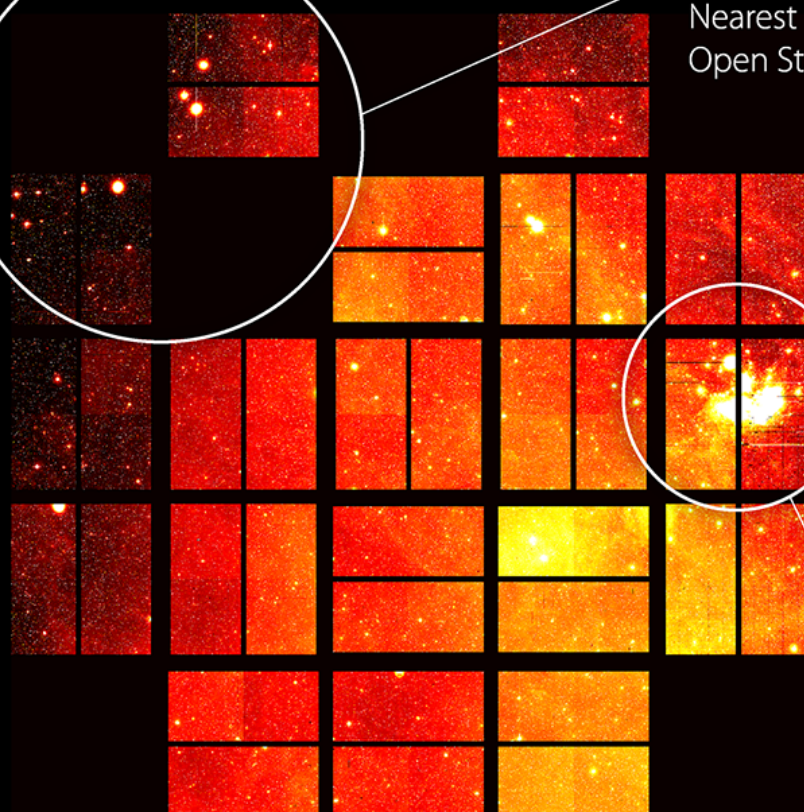


Huber et al. 2016



Vanderburg et al. 2015

CAMPAIGN 4

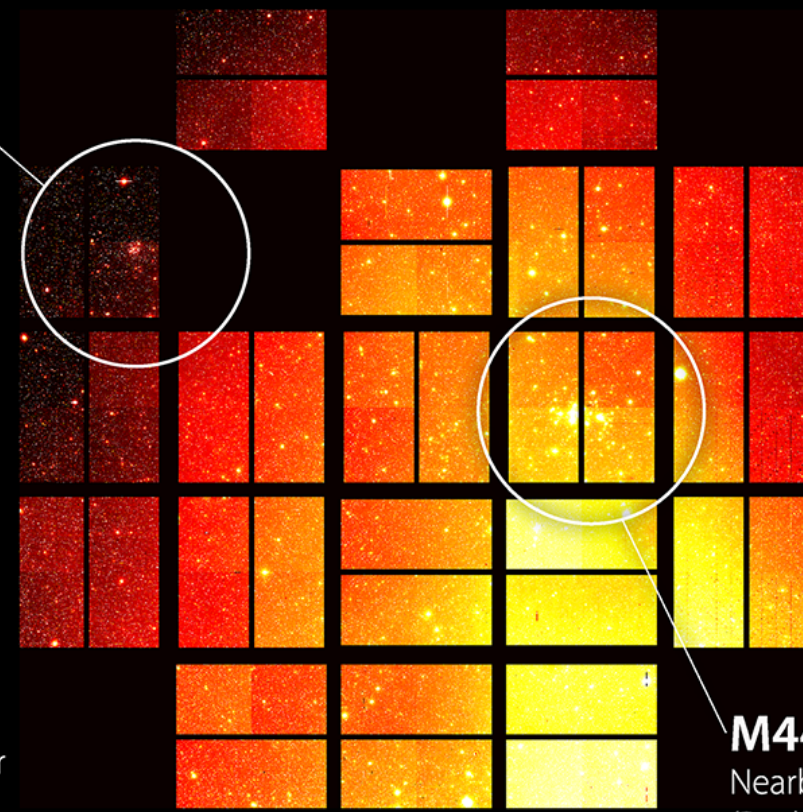


HYADES

Nearest
Open Star Cluster

M67
Nearest Old
Open Star Cluster

CAMPAIGN 5



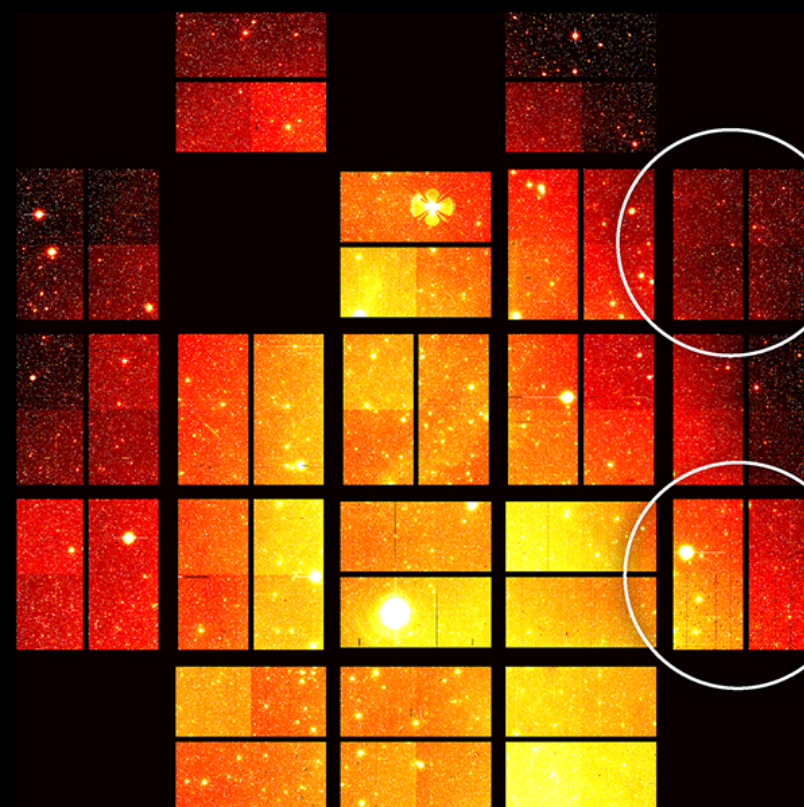
PLEIADES

Nearby Open Star Cluster
(Seven Sisters)

M44

Nearby Open Star Cluster
(Beehive Cluster)

CAMPAIGN 6



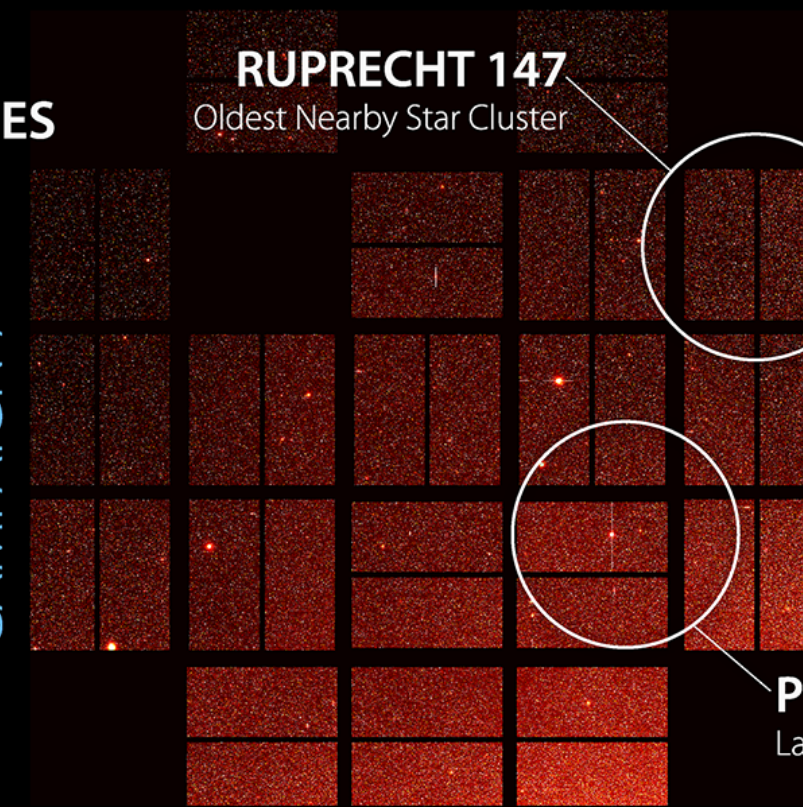
COMA BERENICES

Galaxy Cluster

QATAR-2b

Transiting Exoplanets

CAMPAIGN 7

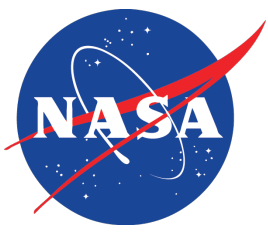


RUPRECHT 147

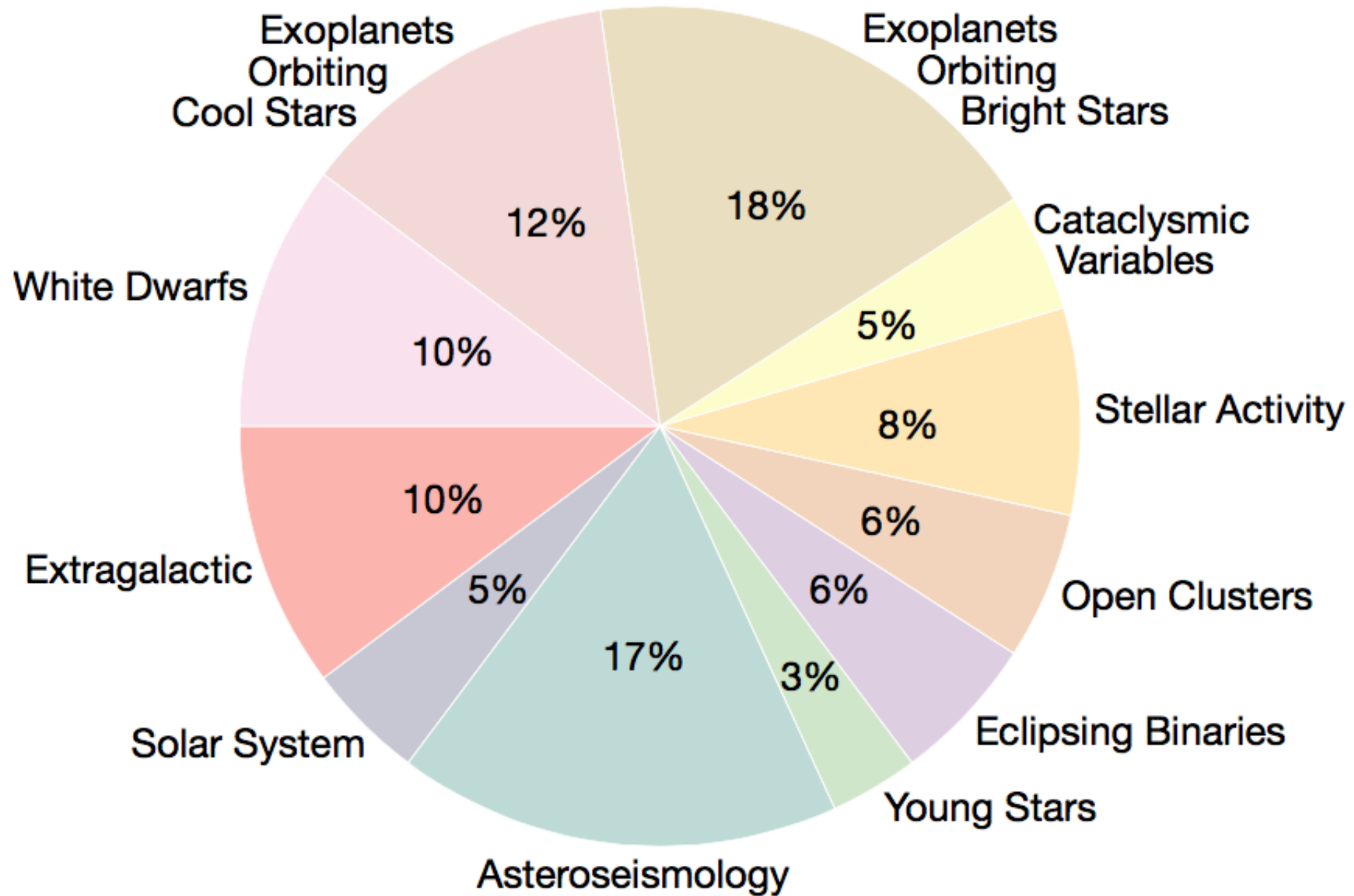
Oldest Nearby Star Cluster

PLUTO

Largest Dwarf Planet



Science Topic of Selected Programs



KEPLER & K2

Science Center

The missions

Kepler & K2 provide long-baseline, high-precision photometry for exoplanet and astrophysics research.

[More »](#)

K2 observing

K2 is a community-driven mission: targets and funding are awarded through open calls for proposals.

[More »](#)

Data analysis

Pixel data, lightcurves, and analysis software are publicly available with no proprietary period.

[More »](#)

News for scientists

K2 Cycle 4: Highlights in future fields

03 Jan 2016

Proposals for targets to be observed by K2 in Campaigns 11, 12, and 13 are currently being solicited as part of [K2 Guest Observer Cycle 4](#). Step 1 submissions for these proposals are due on **February 5, 2016**.

The [fields of these campaigns](#) will cover roughly 100 square degrees at ...

[More »](#)

K2 Cycle 4: Target selection tools

02 Jan 2016

Proposals for targets to be observed by K2 in Campaigns 11, 12, and 13 are currently being solicited as part of [K2 Guest Observer Cycle 4](#). Step 1 submissions for these proposals are due on **February 5, 2016**.

Key information

[K2: Campaign fields »](#)

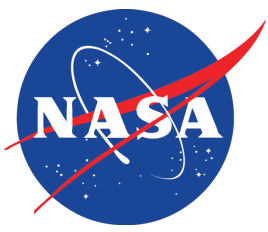
[K2: Observed programs »](#)

[K2: Proposing targets »](#)

[K2: Discretionary time »](#)

[Kepler/K2: Data products »](#)

[Kepler/K2: Publications »](#)



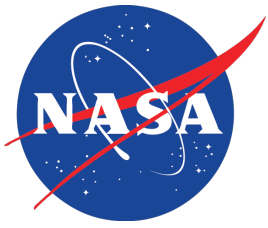
More information on executed programs



Programs that contributed to the Campaign 8 target list

Click on a title to view the abstract. Click on the number of targets to download the target list.

Program	PI	Title	Targets
GO8001	Edelson	AGN Variability Studies with Kepler K2 Campaigns 8 and 10	85
GO8002	Campante	Asteroseismology of solar-type stars with K2	41
GO8003	Smalley	The Am stars: peculiarities, pulsations and planets	2
GO8004	Reed	Understanding extreme horizontal branch stars using asteroseismology; including a known p-mode pulsator and MS companions	7
GO8005	Wehrle	Characterizing the Optical Emission from 3C273 and other quasars	95
GO8006	Kilic	Habitable Planets Around White Dwarfs in Fields 8 and 10	124
GO8007	Silvotti	A survey to detect first sdB Planetary Transits	3
GO8008	Scholz	Rotation of M dwarfs: spindown, activity, and gyrochronology	25
GO8010	Ryan	Lightcurves of Hilda asteroids: Tracing migrations in the early solar system	4847



Our Products

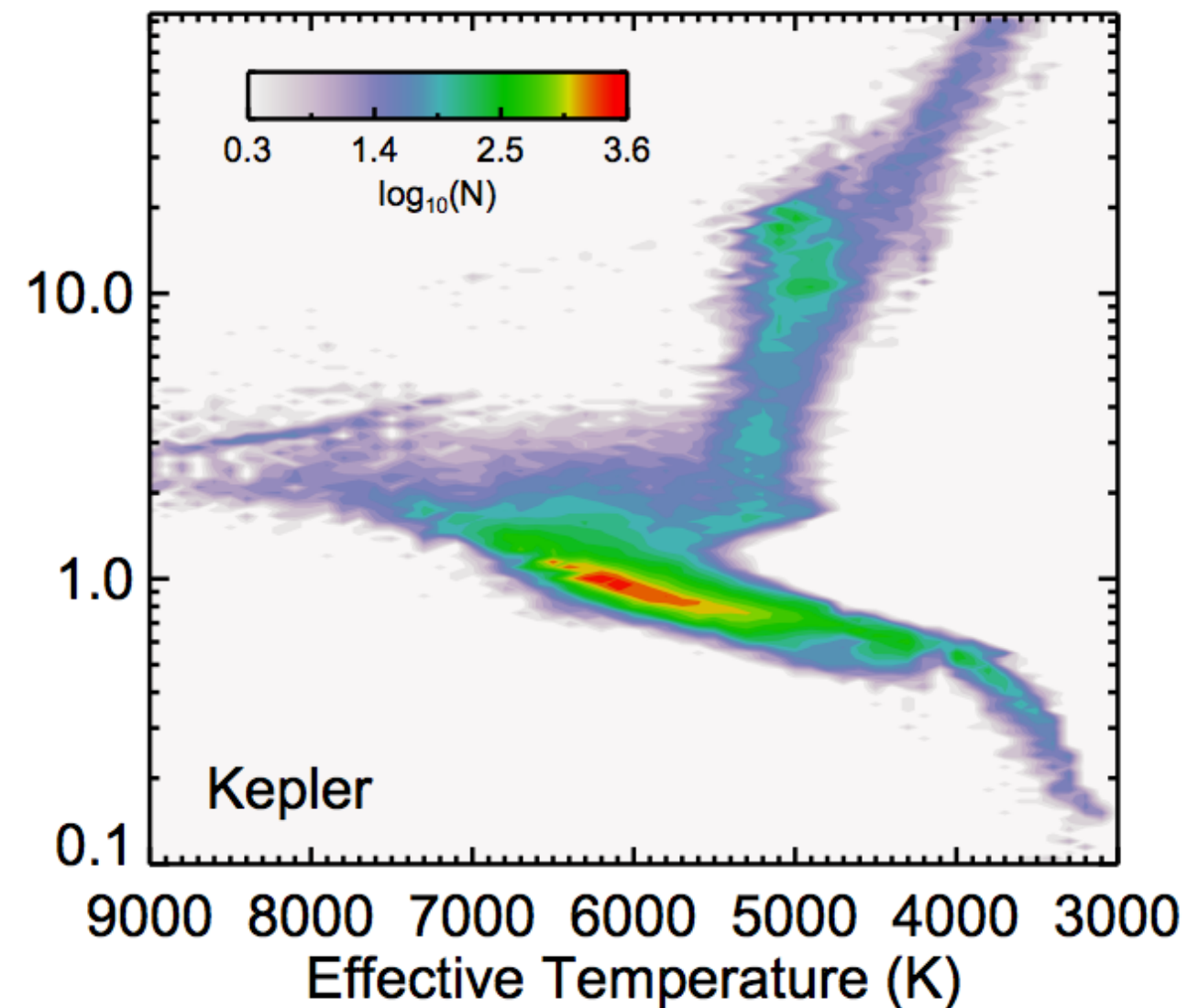
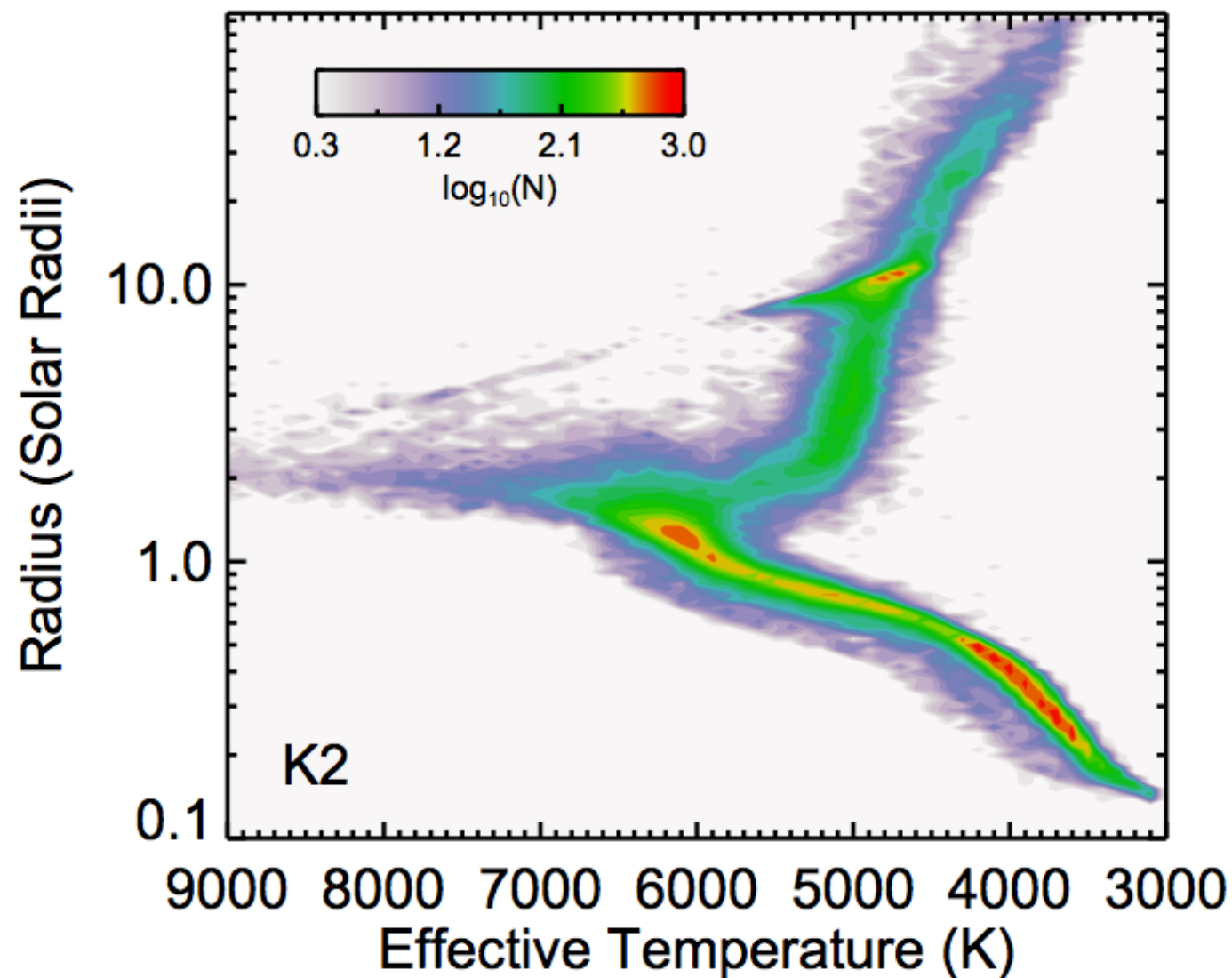


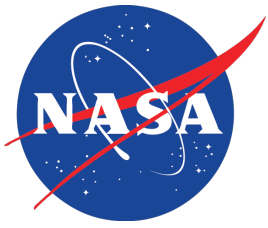


Stellar properties for all targets observed in Campaigns 1–7 Improved catalogs at MAST

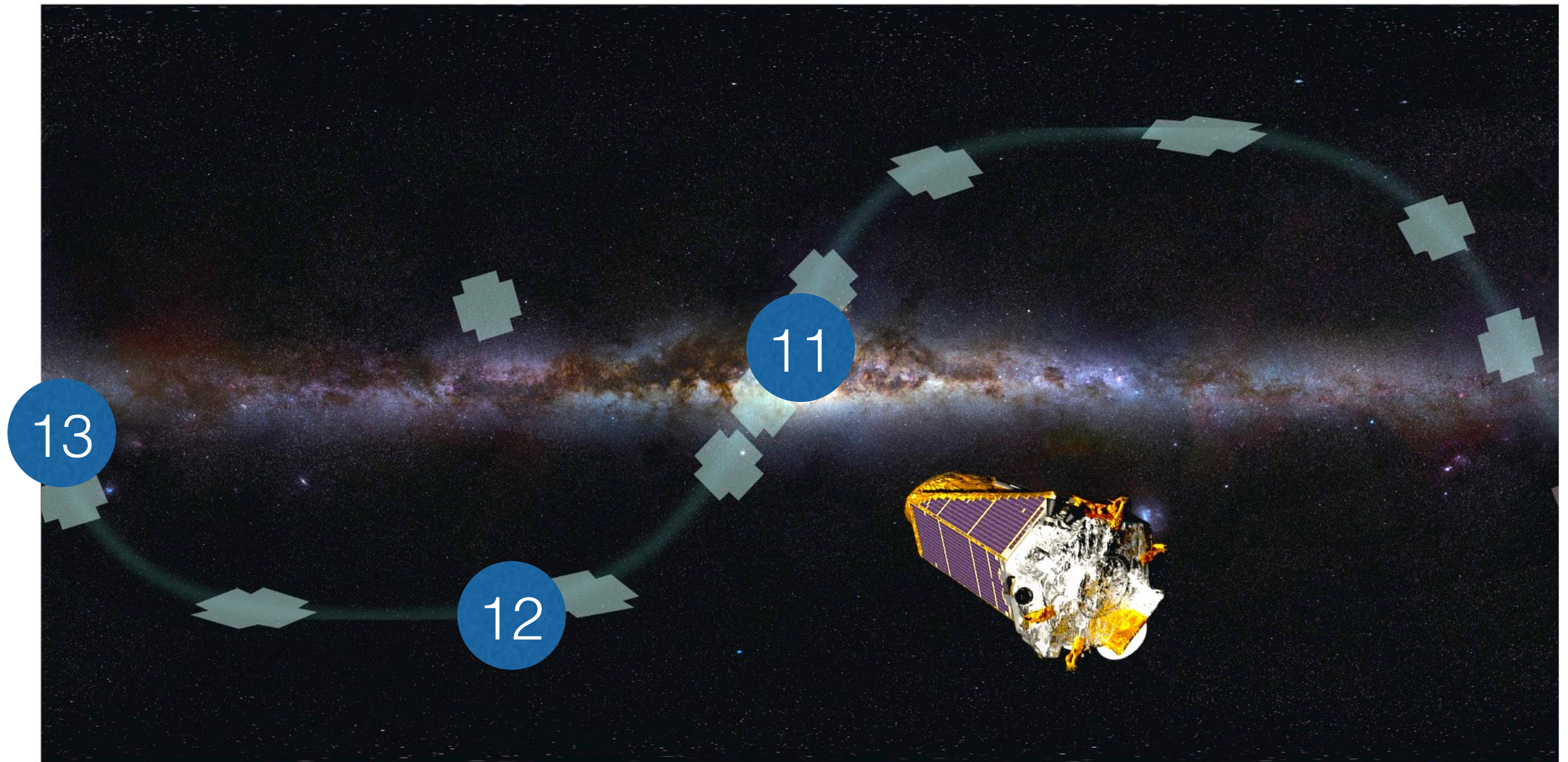


Huber et al 2016

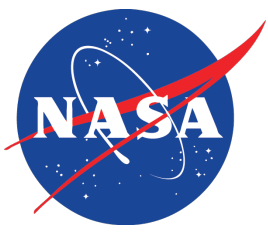




K2 Cycle 4

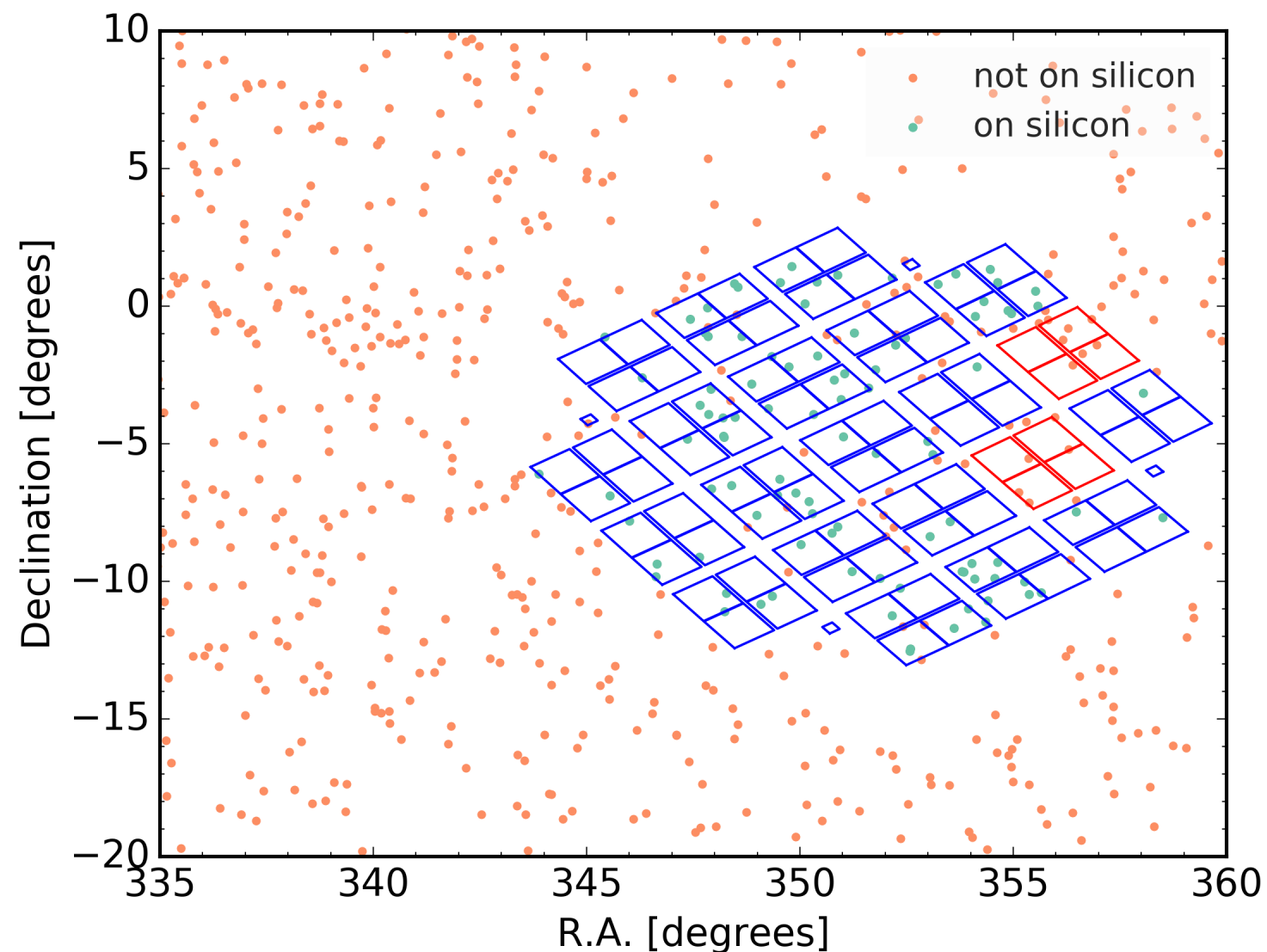


- Cycle 4 is for targets falling into field for Campaigns 11-12-13
- Step-1 deadline: **Feb 5, 2016**
- Step-2 deadline: Mar 4, 2016
- Funding via formula with grants range from \$30,000 to \$150,000

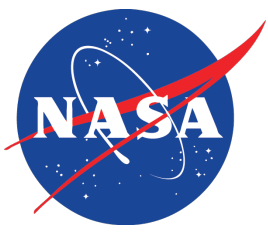


New tools for finding targets

```
$ K2onSilicon mytargetlist.csv 12
```



<http://keplerscience.arc.nasa.gov/software.html>

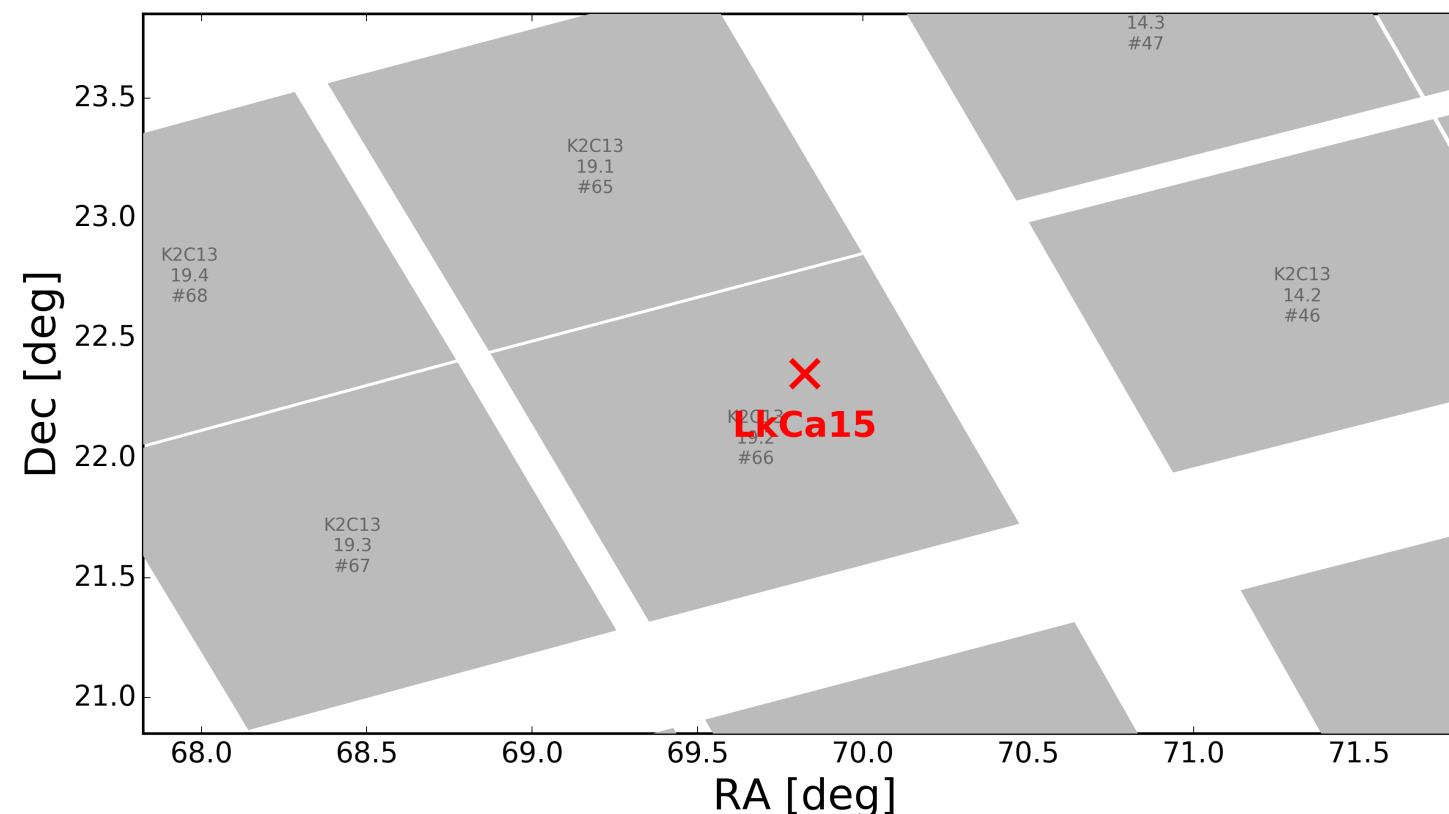


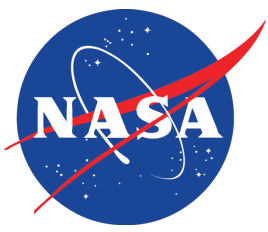
New tools for finding targets

```
$ K2onSilicon mytargetlist.csv 12
```

```
$ K2findCampaigns-byname LkCa15
```

Success! LkCa15 is on silicon
during K2 campaigns [13].





New tools for finding targets

```
$ K2onSilicon mytargetlist.csv 12
```

```
$ K2findCampaigns-byname LkCa15
```

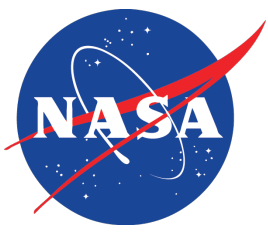
```
Success! LkCa15 is on silicon during K2  
campaigns [13].
```

```
$ K2ephem Enceladus
```

```
Obtaining ephemeris for Enceladus from JPL/  
Horizons...
```

```
Object 'Enceladus' is visible in Campaigns  
[11].
```

<http://keplerscience.arc.nasa.gov/software.html>



'Interesting' targets in upcoming fields

Campaign 11 (Near Galactic Center)

M9 (12 Gyr globular cluster, aka NGC 6333)

BF Oph (classical Cepheid)

Kepler's SN remnant

V2116 Oph (symbiotic star, V=18)

Terzan 5 (global cluster in the bulge)

Saturn

Asteroid Ixion (candidate dwarf planet)

Asteroid Sylvia (has two moons)

Mars Trojan 311999 (moves very fast)

Comet 116P/Wild 4

Campaign 12 (South Galactic Cap)

HIP 116454 (exoplanet host star)

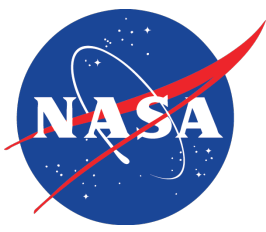
Mars

Comet Chiron (thought to have ring system!!)

Main Belt Comet 118401 LINEAR

Asteroid Itokawa (visited by Hayabuse in 2005)

Comet 53P/Van Biesbroeck



'Interesting' targets in upcoming fields

Campaign 13 (~Galactic anti-center)

Aldebaran (famous K giant, $V=0$)

Taurids (young star forming region), includes:

- HL Tau (protoplanetary disk famously imaged by ALMA, $V=15$)
- AA Tau (contains unconfirmed transiting $M = 20 M_{\text{Jup}}$ companion, $V=12$)
- V1213 Tau (associated with the pretty Herbig Haro outflow HH 30)
- LkCa15 (thought to show an actively-forming exoplanet in direct imaging)
- XZ Tau (binary young system which showed a superflare in 2000)
- HBC 393 (FUOr; extremely variable abrupt mass accretion events)

Hyades (open cluster), includes:

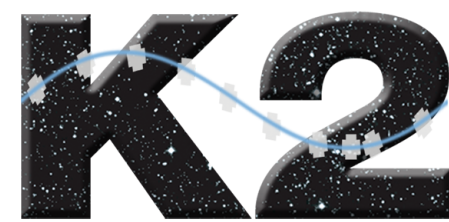
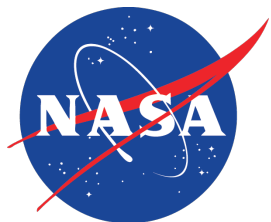
- eps Tau (bright Hyades member with known RV planet, $V=4$)

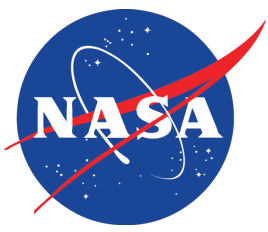
NGC 1647, 1746, 1750, 1802, 1807 (open clusters, poorly studied?)

NGC 1817 (1 Gyr open cluster, 2 kpc)

Asteroid Annefrank (visited by the Stardust spacecraft in 2002)

2040 M-type stars;
1270 RR Lyr Variables;
1219 Quasars;
727 High proper-motion stars
280 Mira Variables;
252 Young Stellar Objects;
167 Active Galactic Nuclei;
152 White Dwarfs (3 pulsating);
133 Herbig Haro Objects;
71 T Tauri Stars;
57 Brown Dwarfs;
29 Blue Stragglers;
18 O-type stars;
16 Cataclysmic Variables;
11 Symbiotic Stars;
4 Wolf Rayet stars;
1 FU Orionis variable.





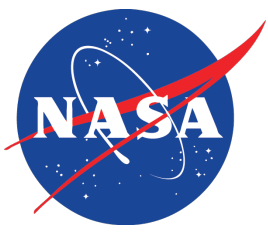
The DDT Program

The K2 DDT program facilitates observations that:

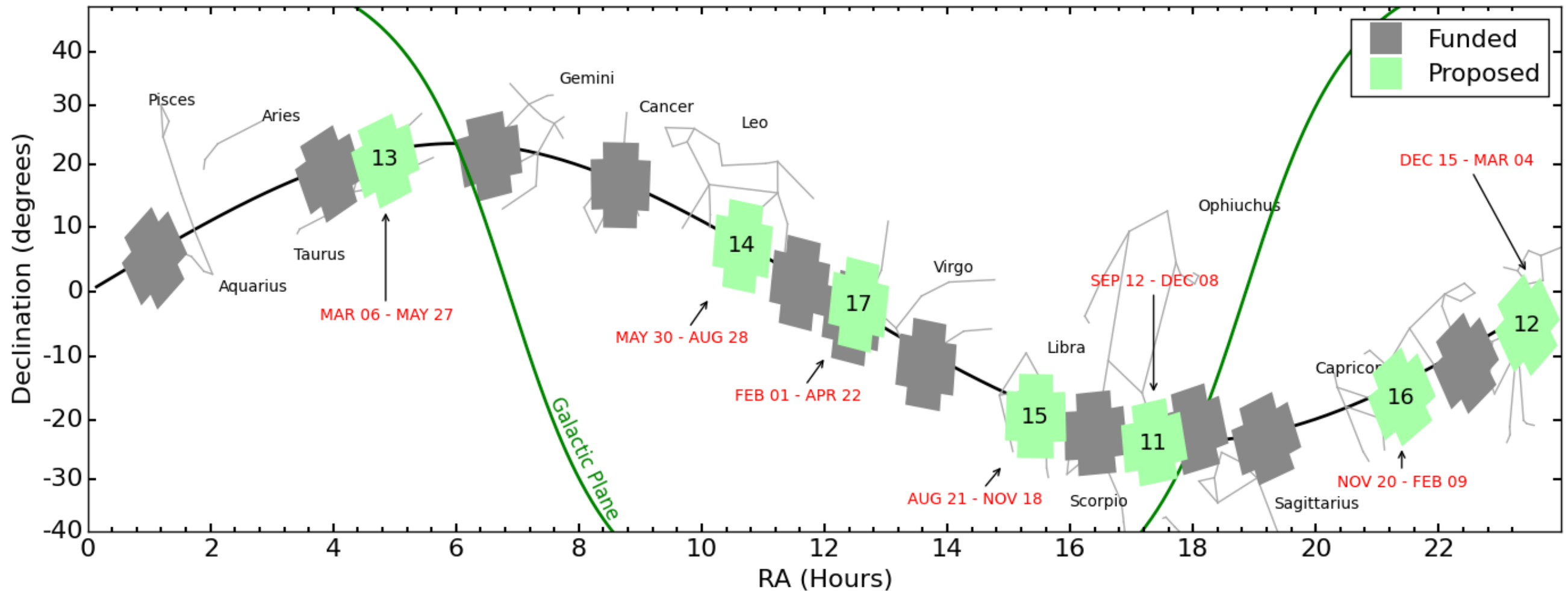
- respond to targets of opportunity
- yield high-impact science from K2
- enhance existing GO programs with additional critical data
- **March 10, 2016 for Campaign 10**

In C9 we had 23 DDT proposals

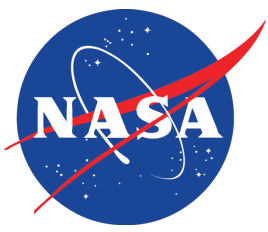
<http://keplerscience.arc.nasa.gov/k2-ddt.html>



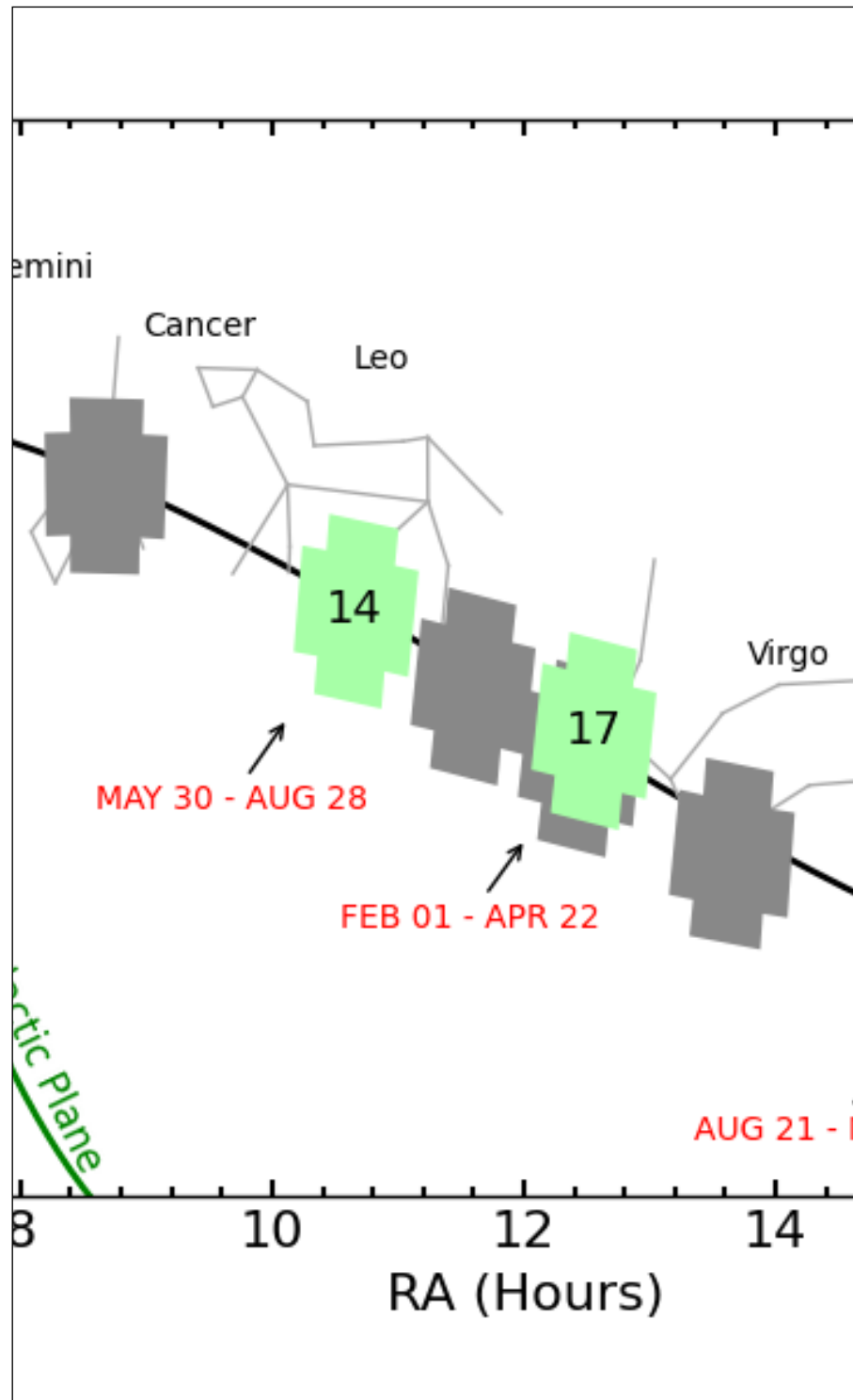
Advocate for future fields



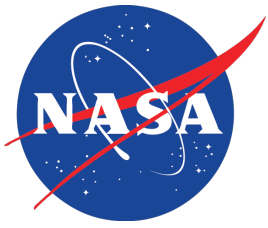
- Positions of fields for Campaign 14-18 are not yet set
- Contact us to advocate for changes
 - keplergo@mail.arc.nasa.gov
 - keplerscience.arc.nasa.gov



A forward facing field in C17



- A forward facing field in C17
- Starting in Feb 2018
- Allows for simultaneous monitoring from the ground
- Primary motivations are
 - ◆ supernova searches
 - ◆ exoplanet transit timing variations from 2 years previously
 - ◆ (and Trojans?)



Session Outline

- The K2 mission - **Tom Barclay** (NASA Ames)
- Targeting solar system bodies - **Geert Barentsen** (NASA Ames)
- K2 support and the ExoFOP - **Rachel Akeson** (NExSci)
- Observations of Neptune and Uranus - **Amy Simon** (NASA GSFC)
- Pushing the limits of K2: observing distant, small Solar System bodies with Kepler - **Csaba Kiss** (Konkoly Obs., Hungary)
- Trojan Asteroids - **Erin Ryan** (NASA GSFC)
- Q&A (5 mins)



The NASA K2 Mission

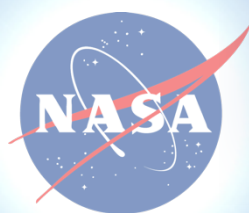
Extending Kepler's Legacy to the Ecliptic



Tom Barclay

NASA Ames Research Center

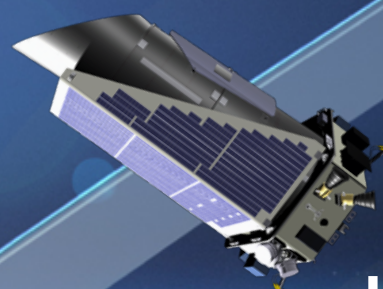
DPS NASA Astrophysics Assets Workshop
Nov 10, 2015



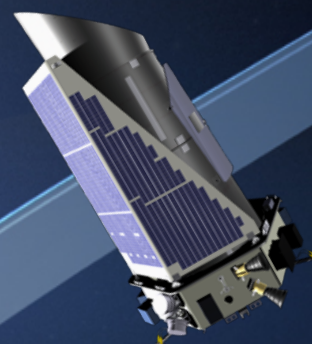
Exoplanet Missions



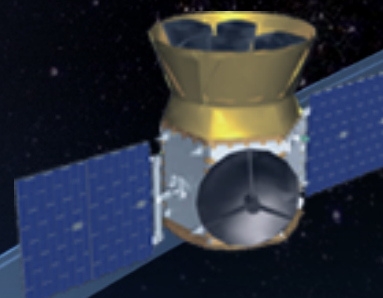
Hubble



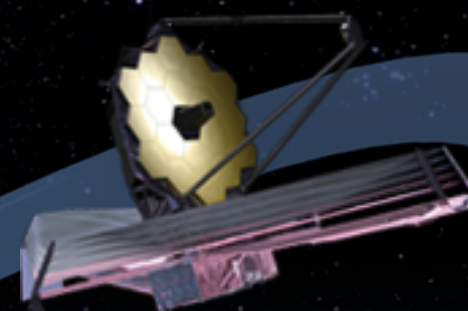
Kepler



K2



TESS



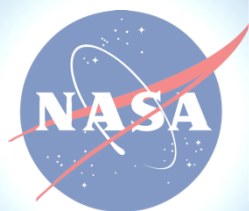
JWST



*New Worlds
Telescope*

Ground-based
Observatories

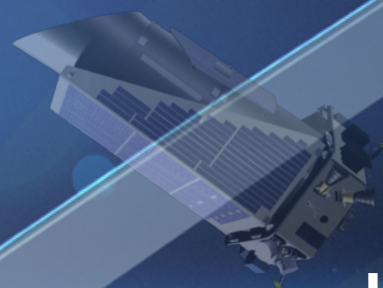
+ Spitzer & WFIRST



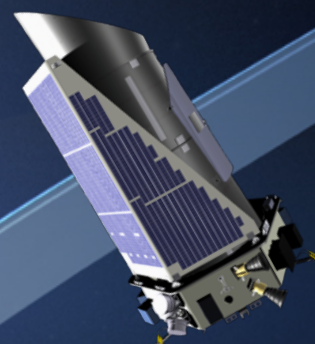
Planetary Science Missions



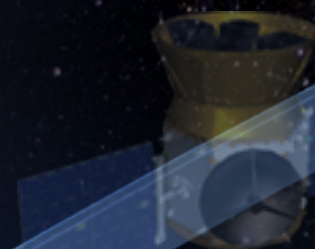
Hubble



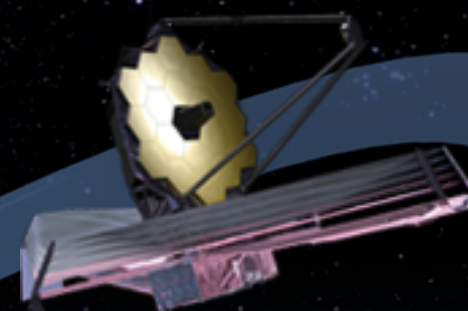
Kepler



K2



TESS



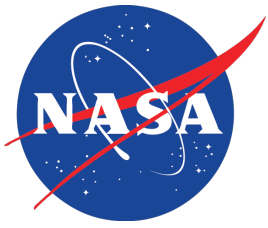
JWST



*New Worlds
Telescope*

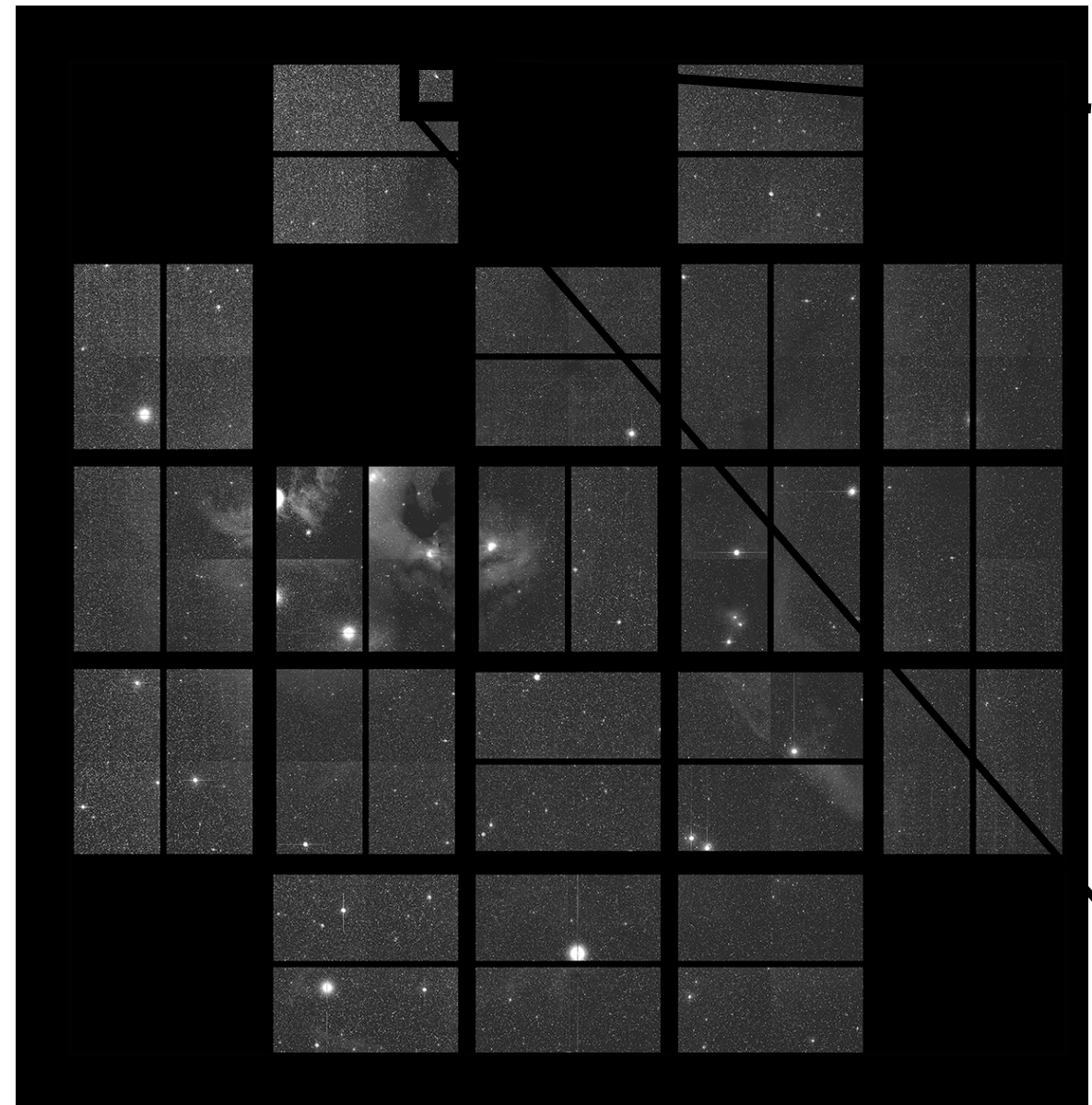
Ground-based
Observatories

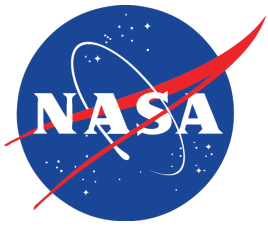
+ Spitzer & WFIRST



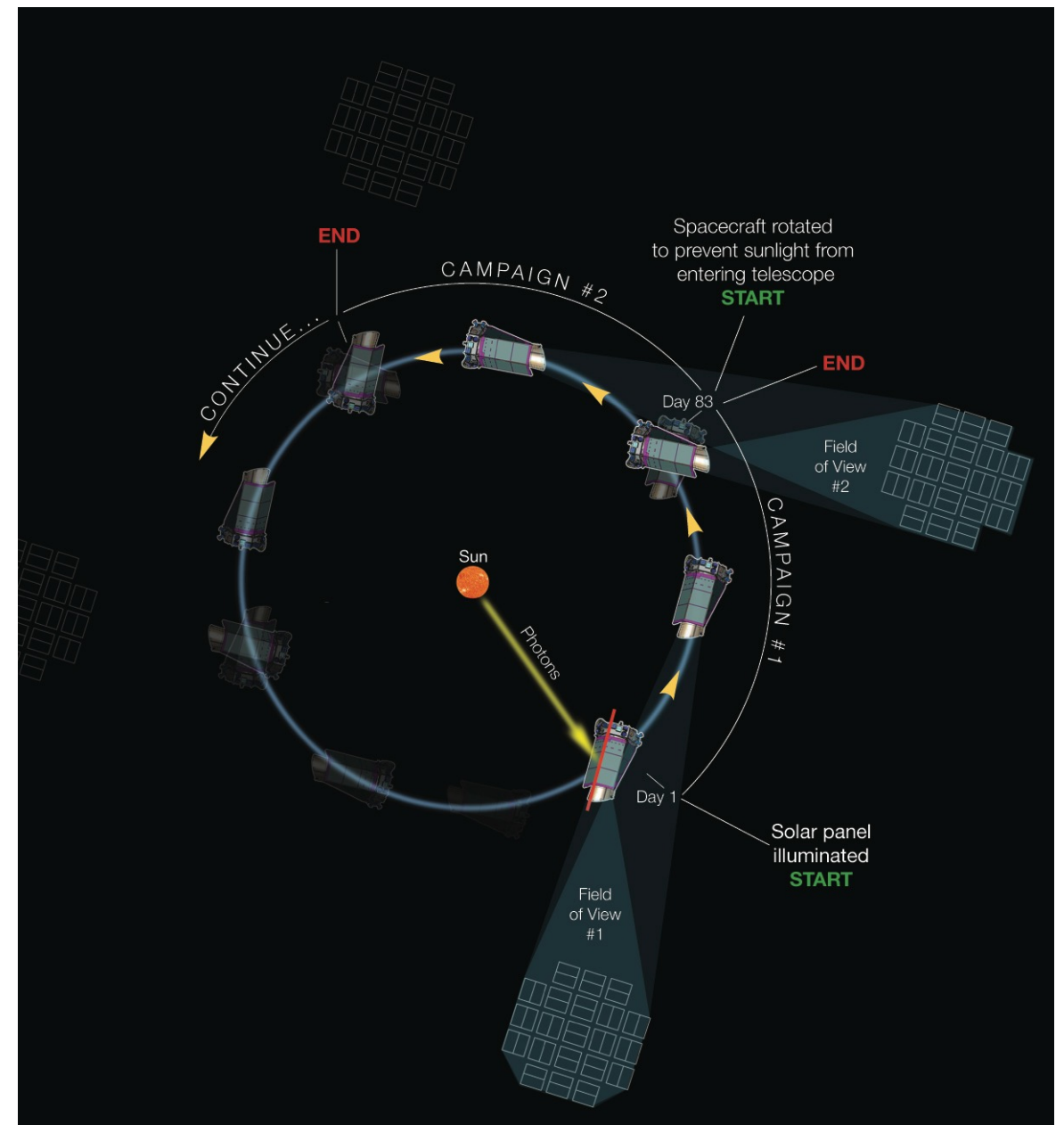
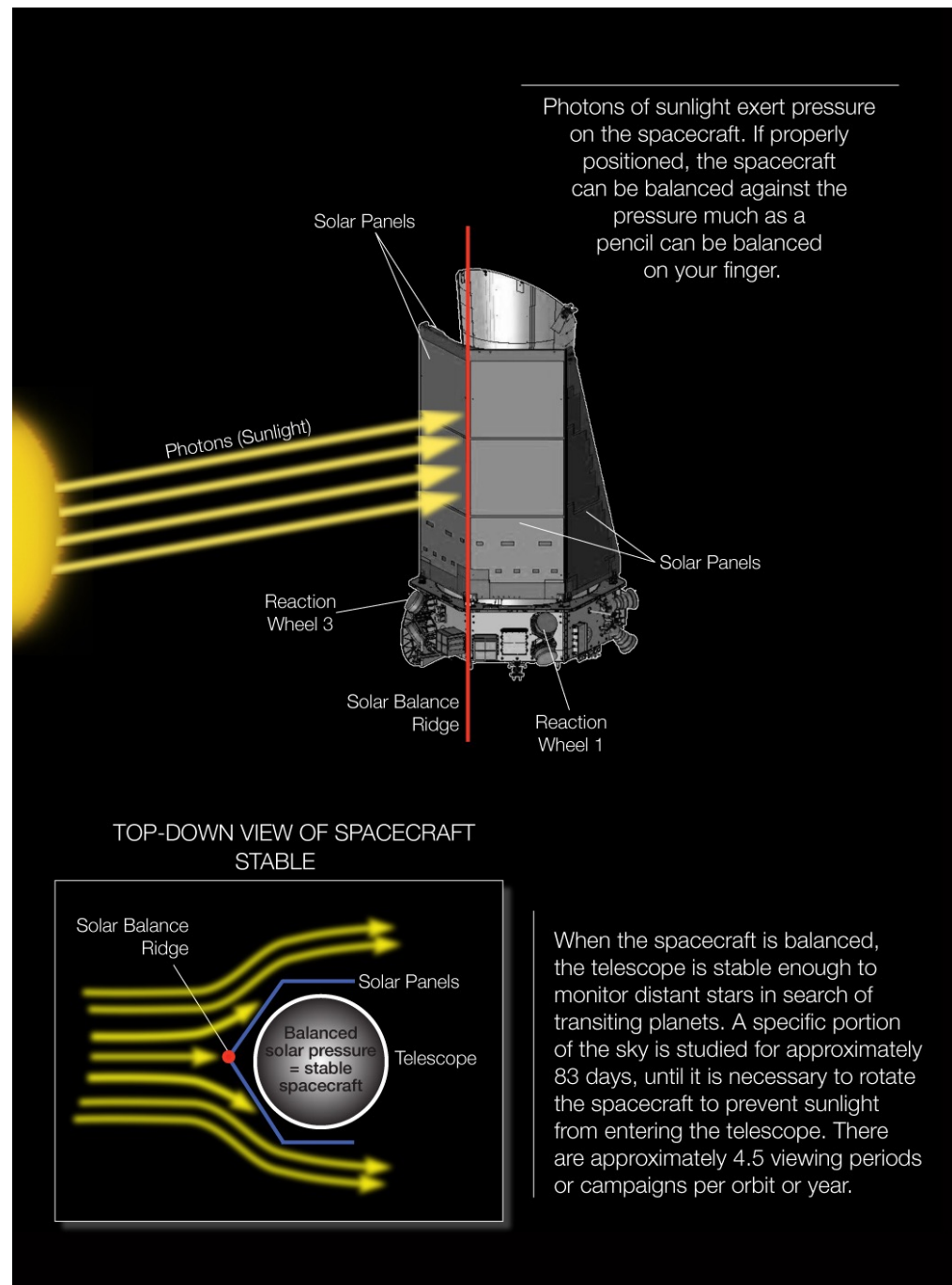
What is K2?

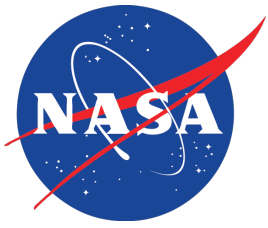
- K2 is a two-reaction wheel controlled mission utilizing the Kepler spacecraft
- We observe 100 sq.deg. fields close to the ecliptic
- Each field is observed for approx. 80 days
- Two exposure modes - 30 min / 1 min
- There is no “K2 mission goal”, all science must be proposed by the community.





What is K2?

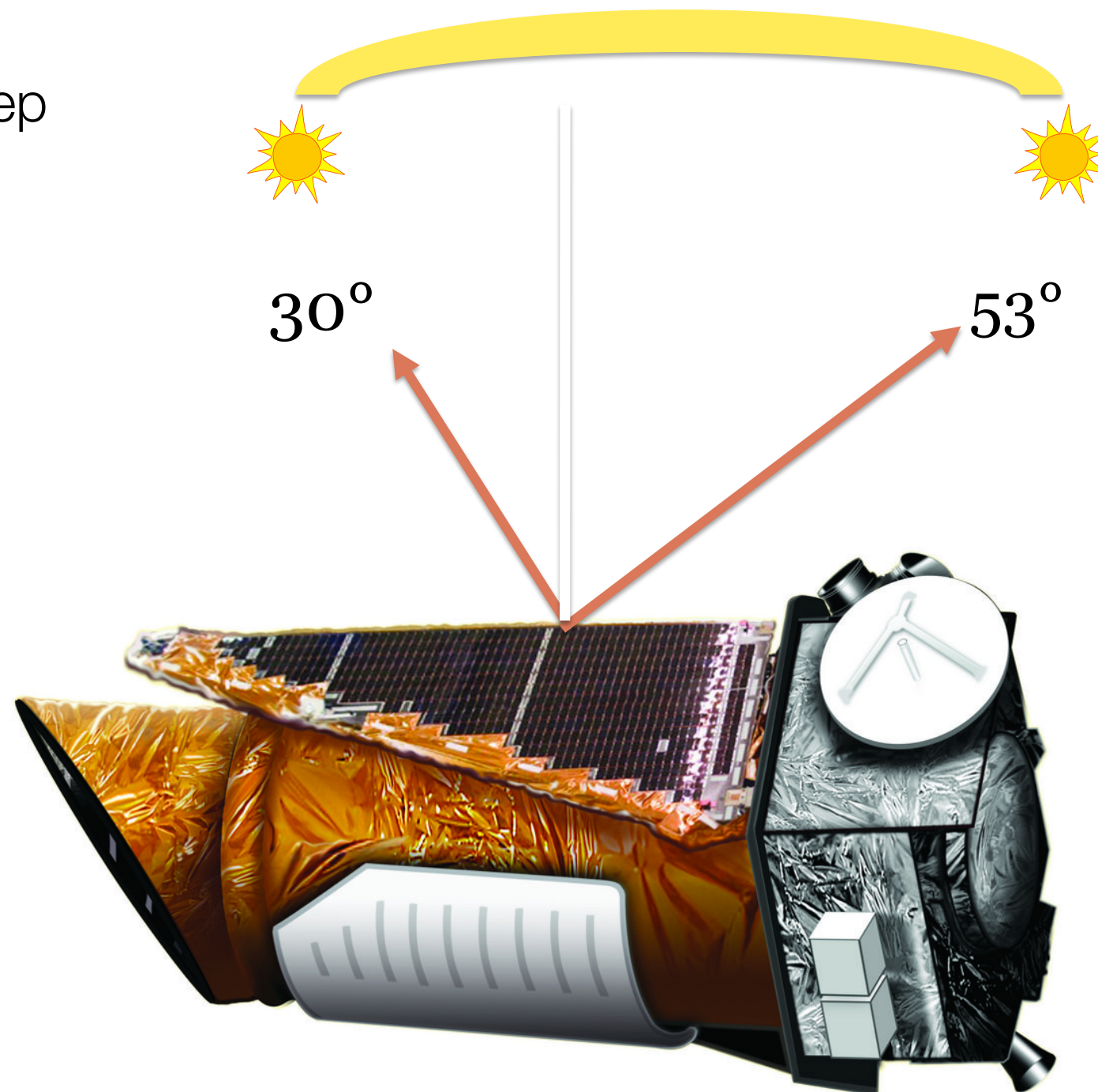




What is K2?

Spacecraft must keep solar panel pointed at the sun.

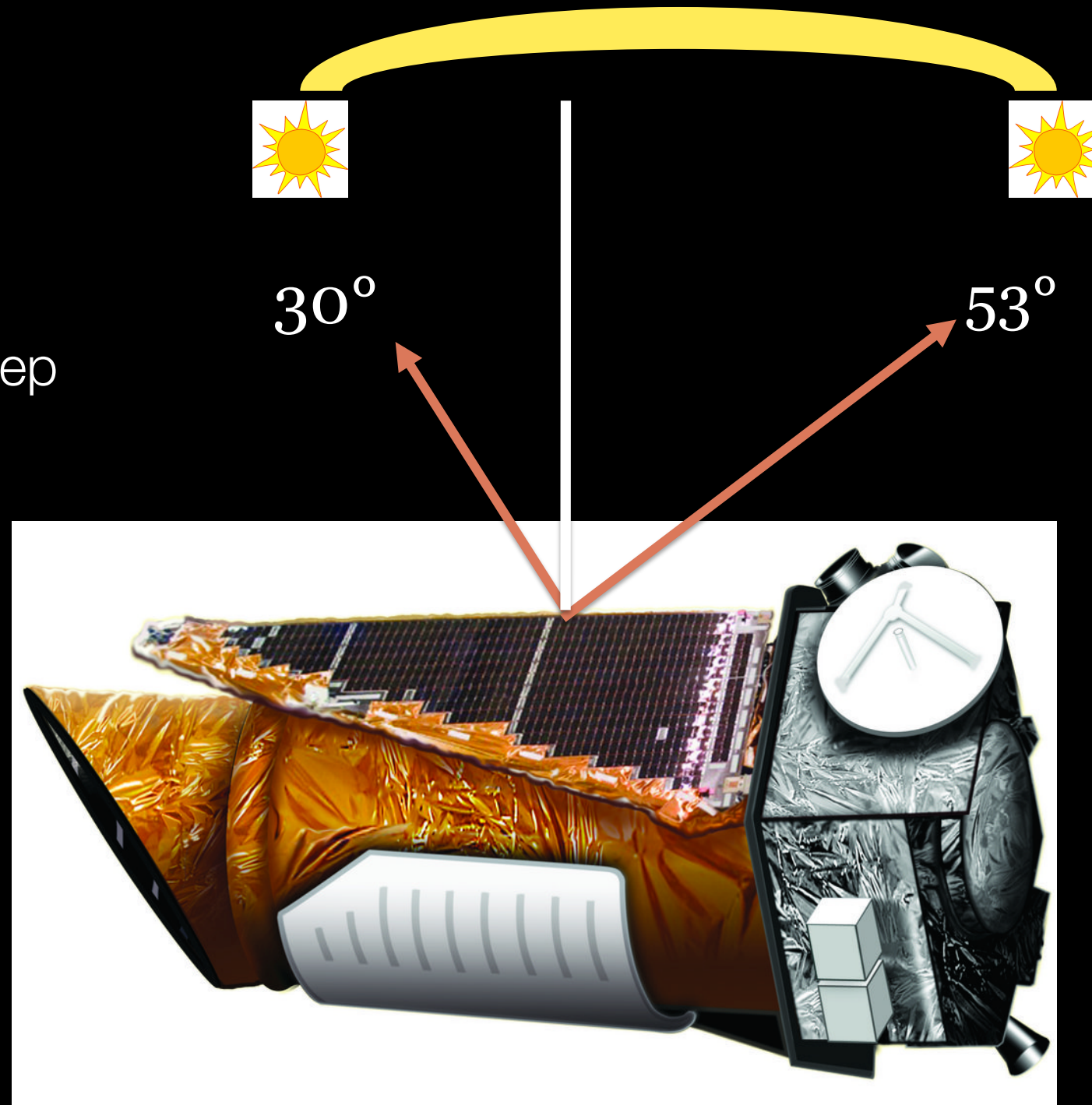
Limits time it can stare at a single field to 80-90 days (depending on the spacecraft orbital phase)

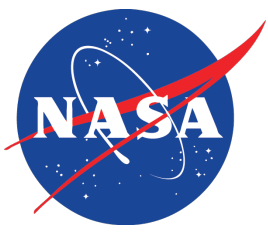


Balancing Solar Pressure

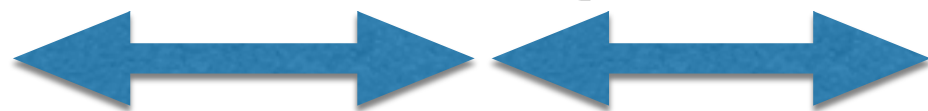
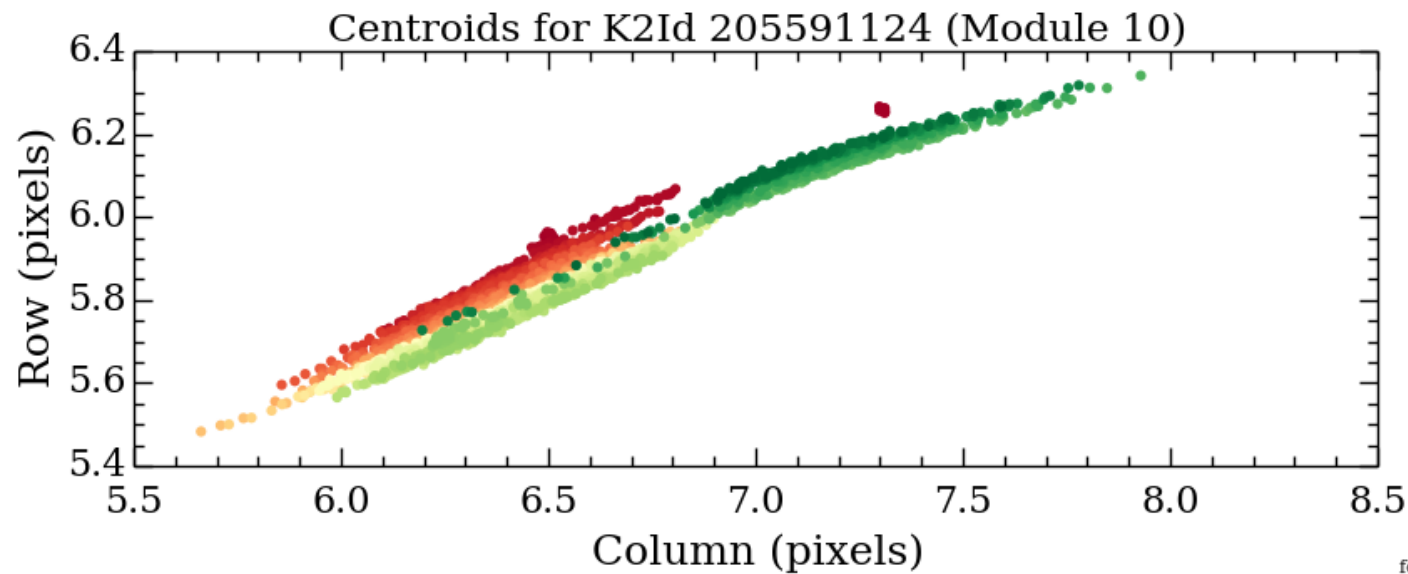
Spacecraft must keep solar panel pointed at the sun.

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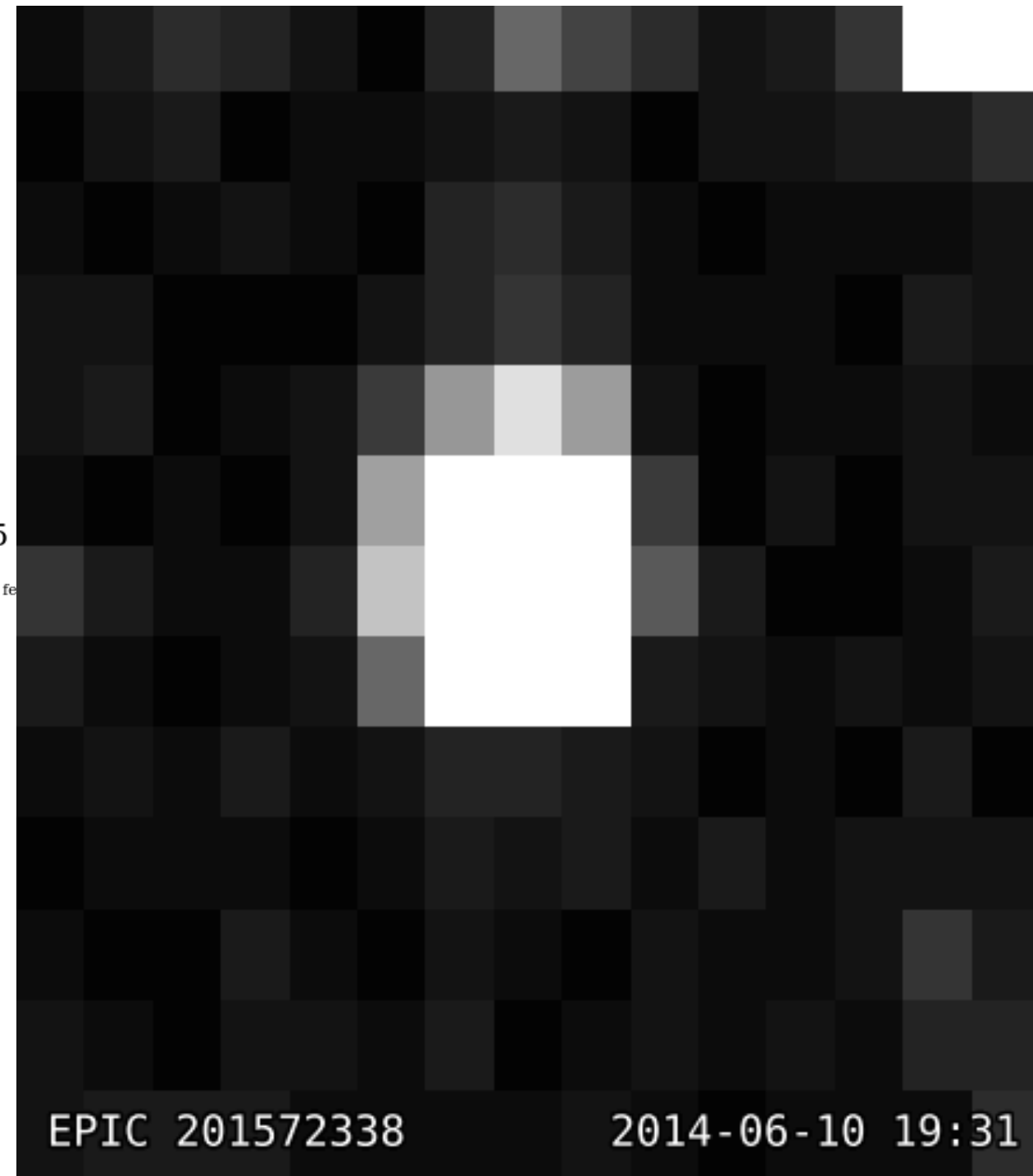


Pointing Performance



First half of campaign Second half of campaign

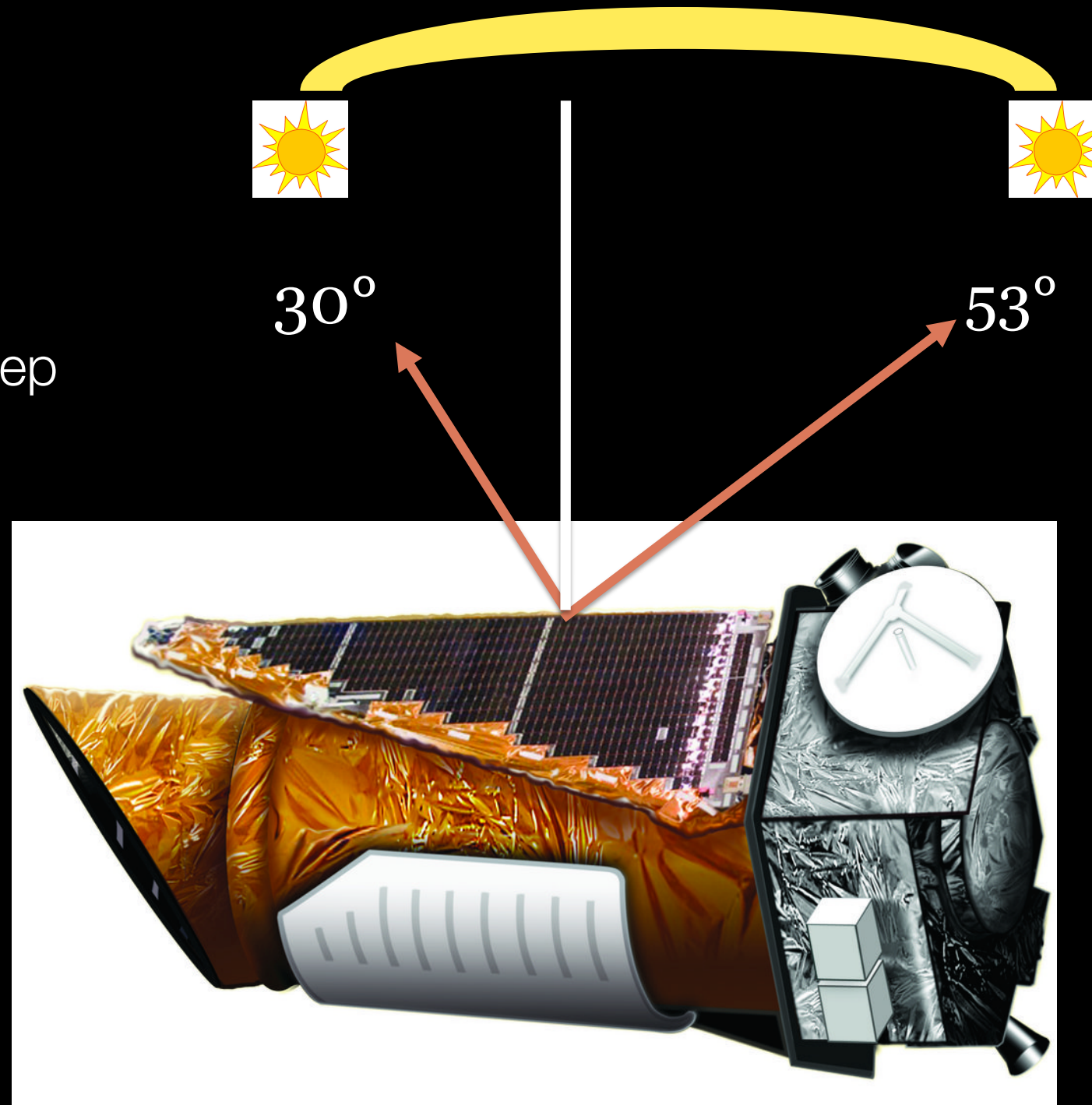
The motion is about a pixel every 6-hours

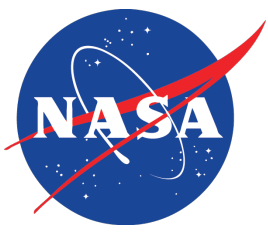


Balancing Solar Pressure

Spacecraft must keep solar panel pointed at the sun.

Limits time it can stare at a single field to 80-90 days (depending on the spacecraft orbital phase)



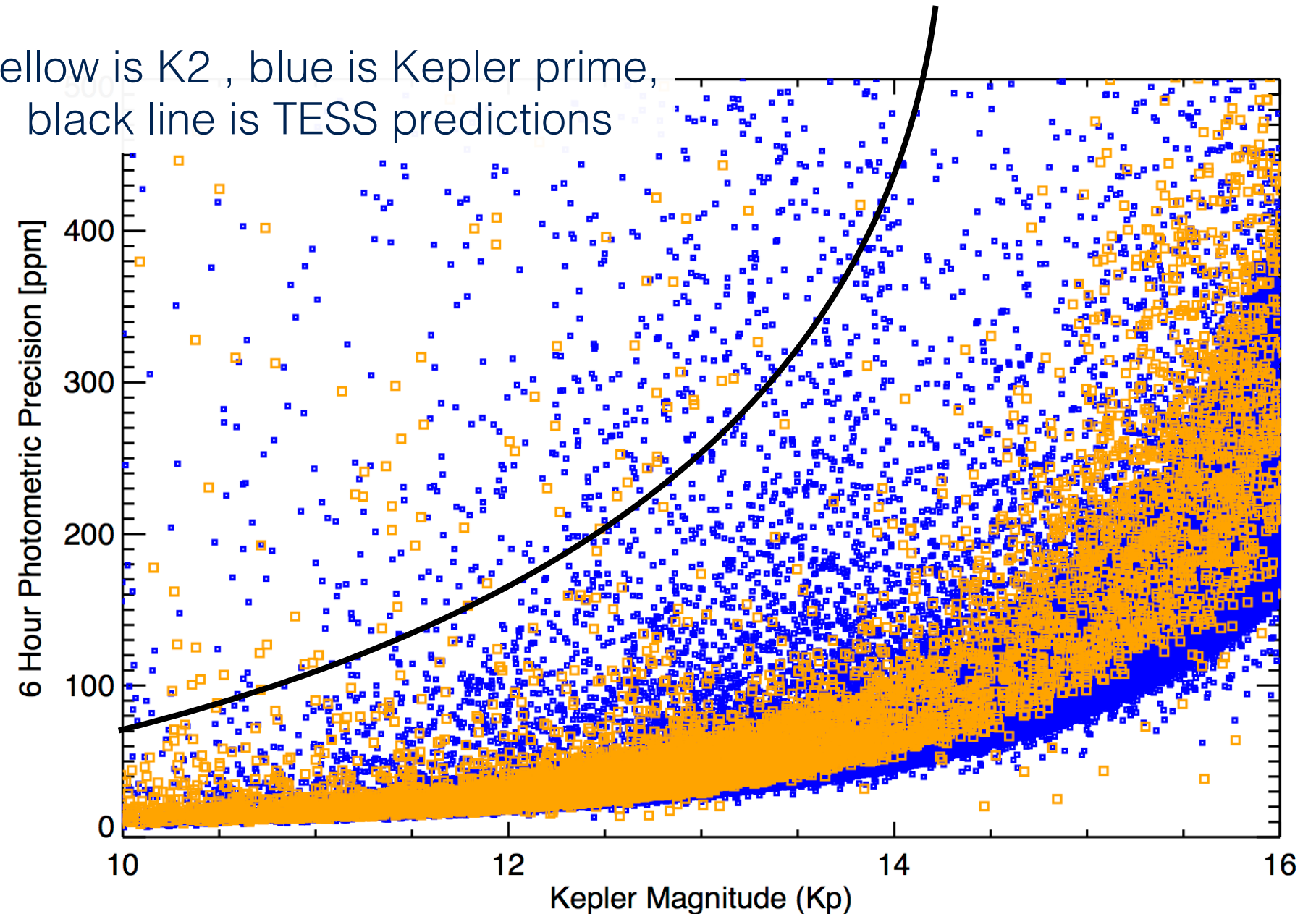


Photometric Performance



Photometric performance from C3 onward is essentially the same as Kepler prime for bright stars

Yellow is K2, blue is Kepler prime, black line is TESS predictions

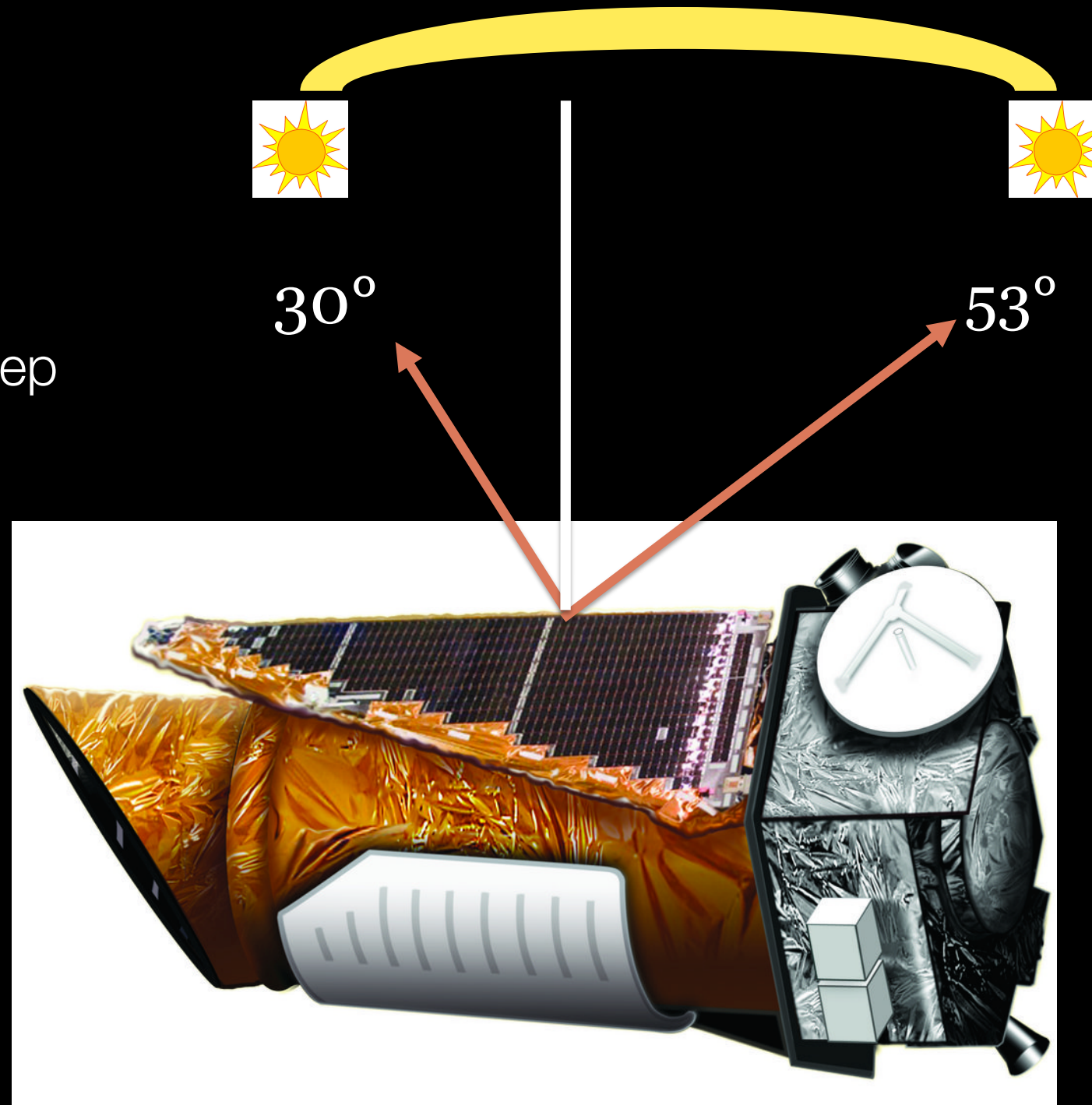


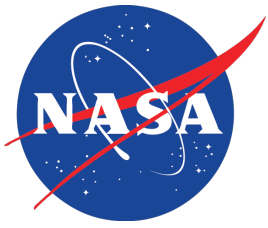
Vanderburg et al. 2015, Ricker et al 2014,
+ Vanderburg, priv. comm.

Balancing Solar Pressure

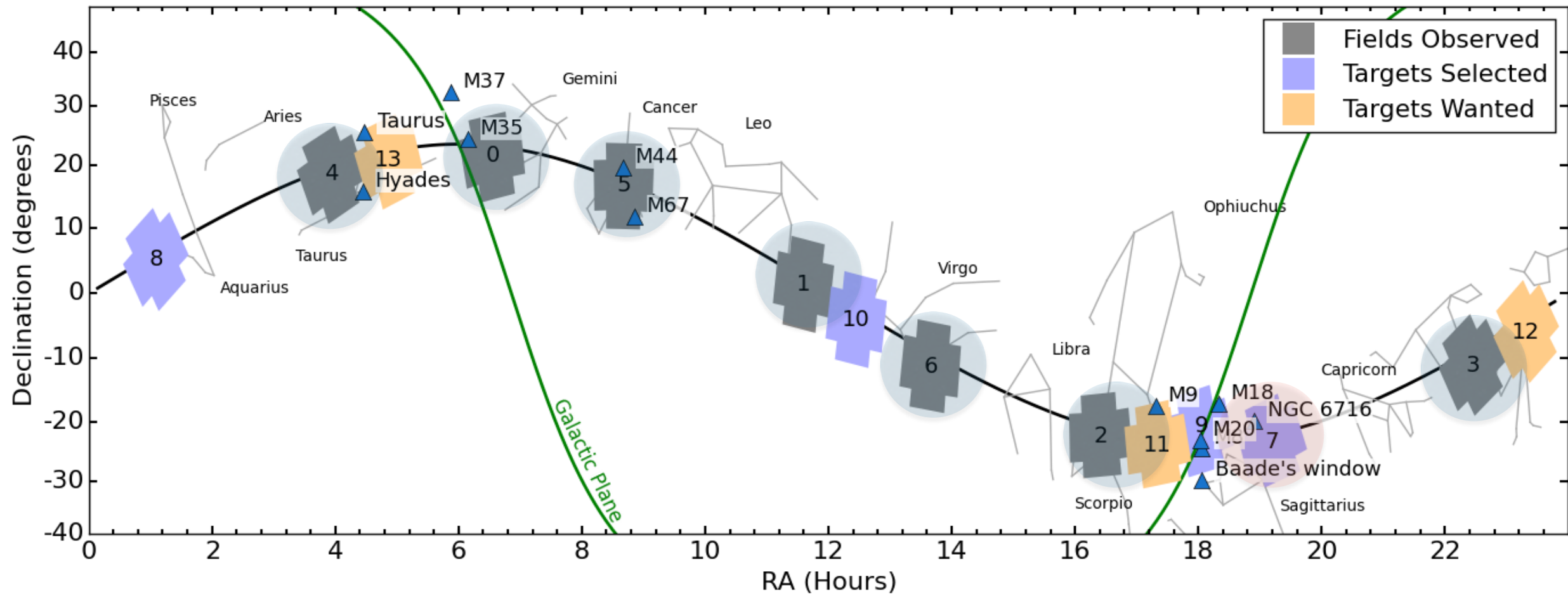
Spacecraft must keep solar panel pointed at the sun.

Limits time it can stare at a single field to 80-90 days (depending on the spacecraft orbital phase)





Current Status



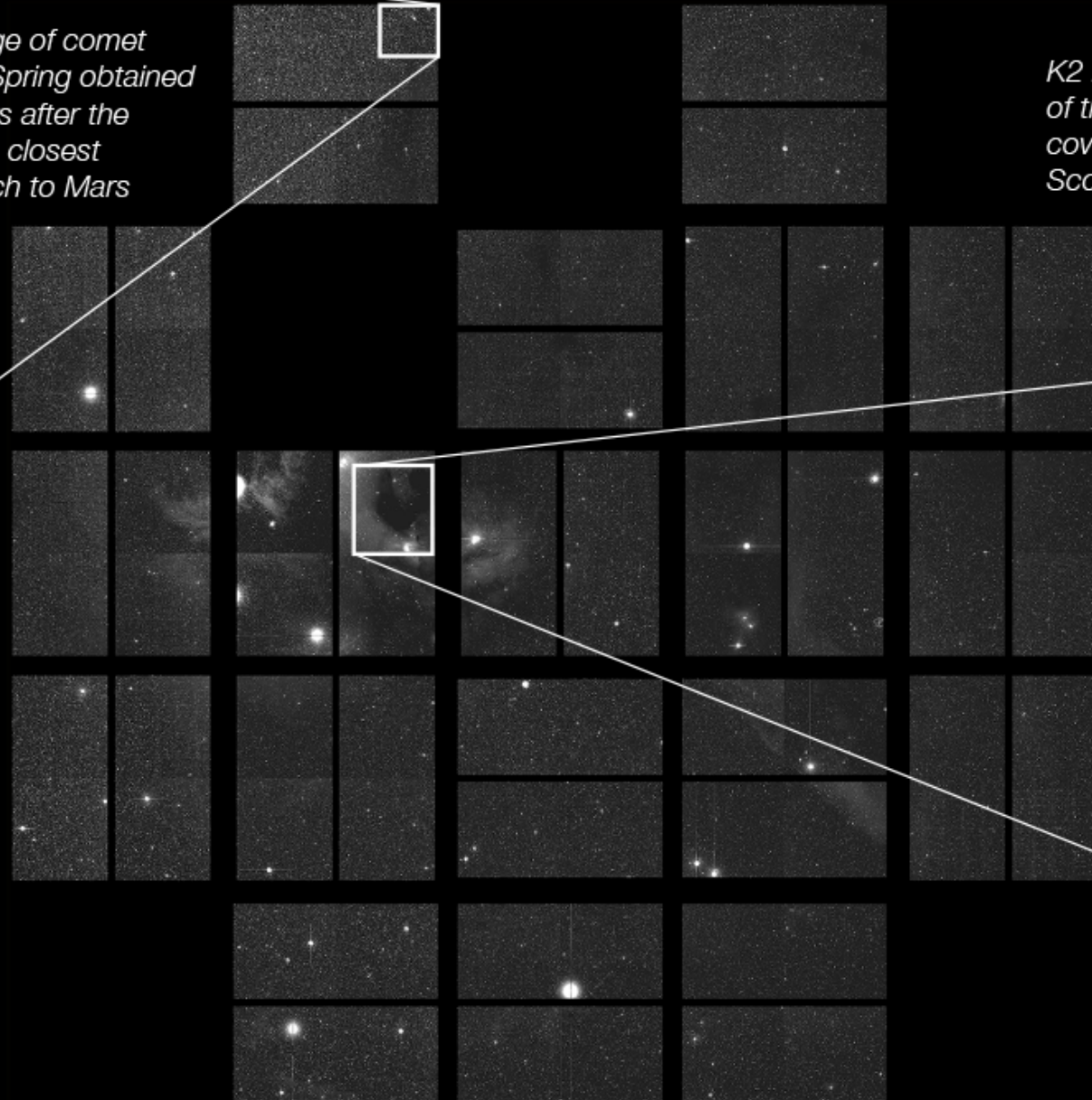
fergal fieldsFor2014.py 2015-08-24 14:53

- Science Programs for C0-C8 are online
- Science data are available for C0-C5
 - ✧ C6 data will be released ~ Jan 25

New Science in K2

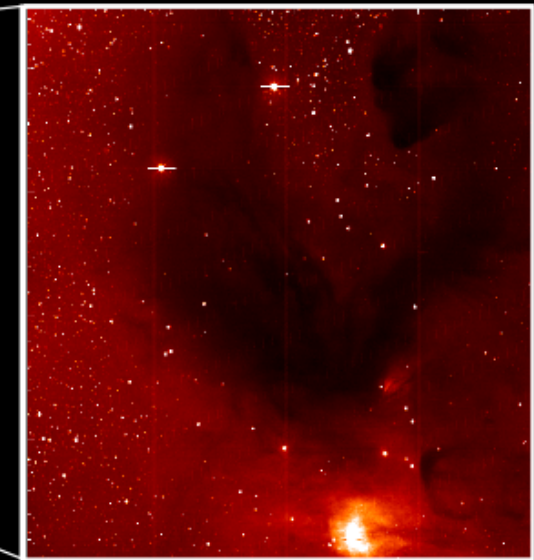
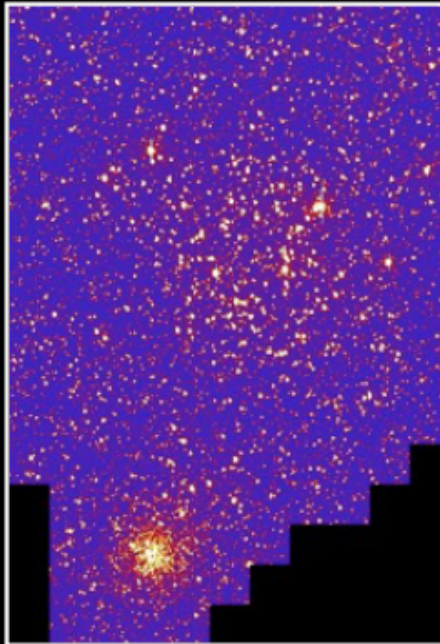


K2 image of comet Siding Spring obtained just days after the comet's closest approach to Mars



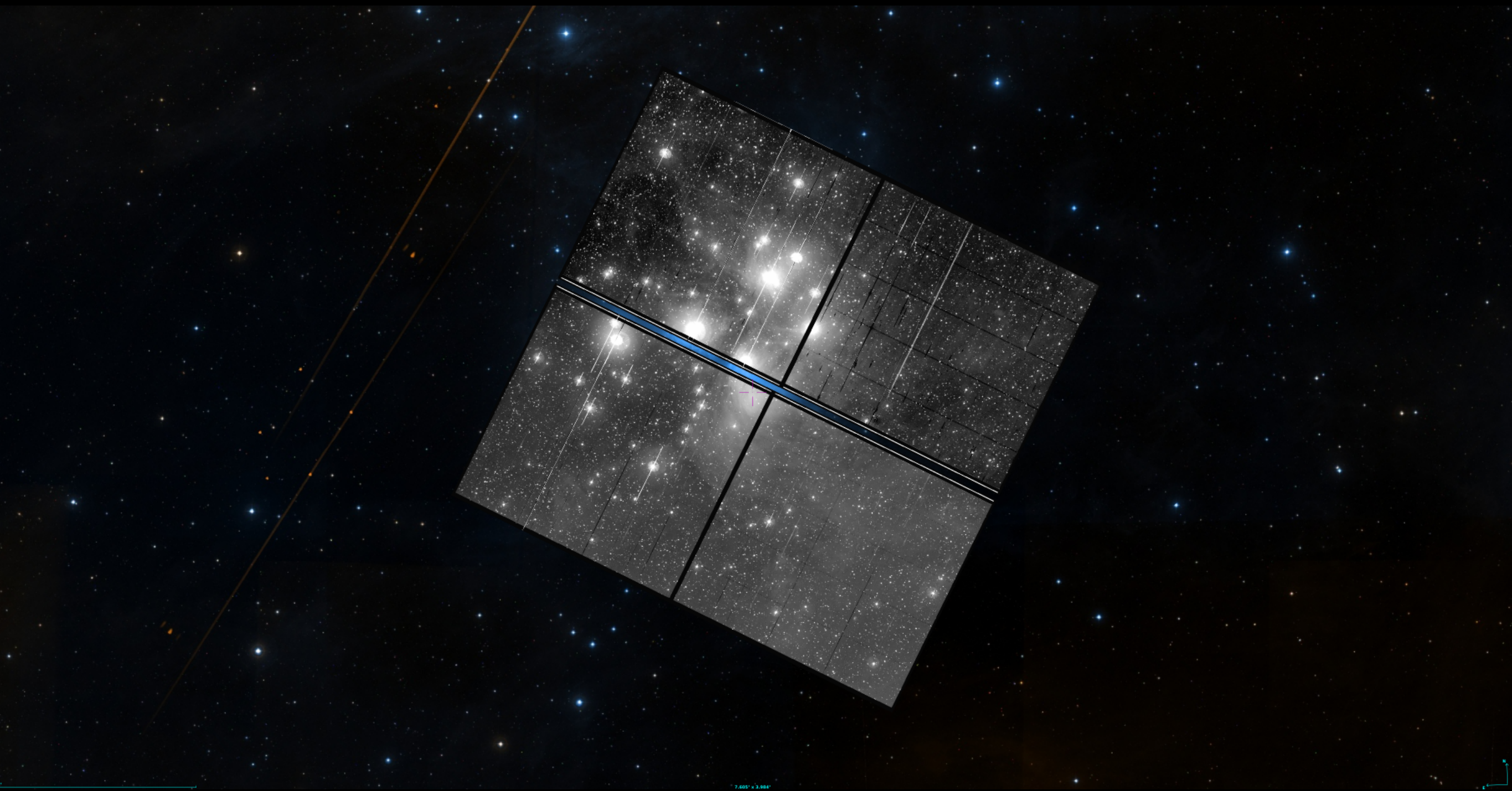
K2 Mission Full Frame Image of the Campaign 2 field of view covering the constellations of Scorpius and Ophiuchus

An image of the young open star cluster M35 and the open cluster NGC 2158. Image is from K2's first full-length engineering campaign.

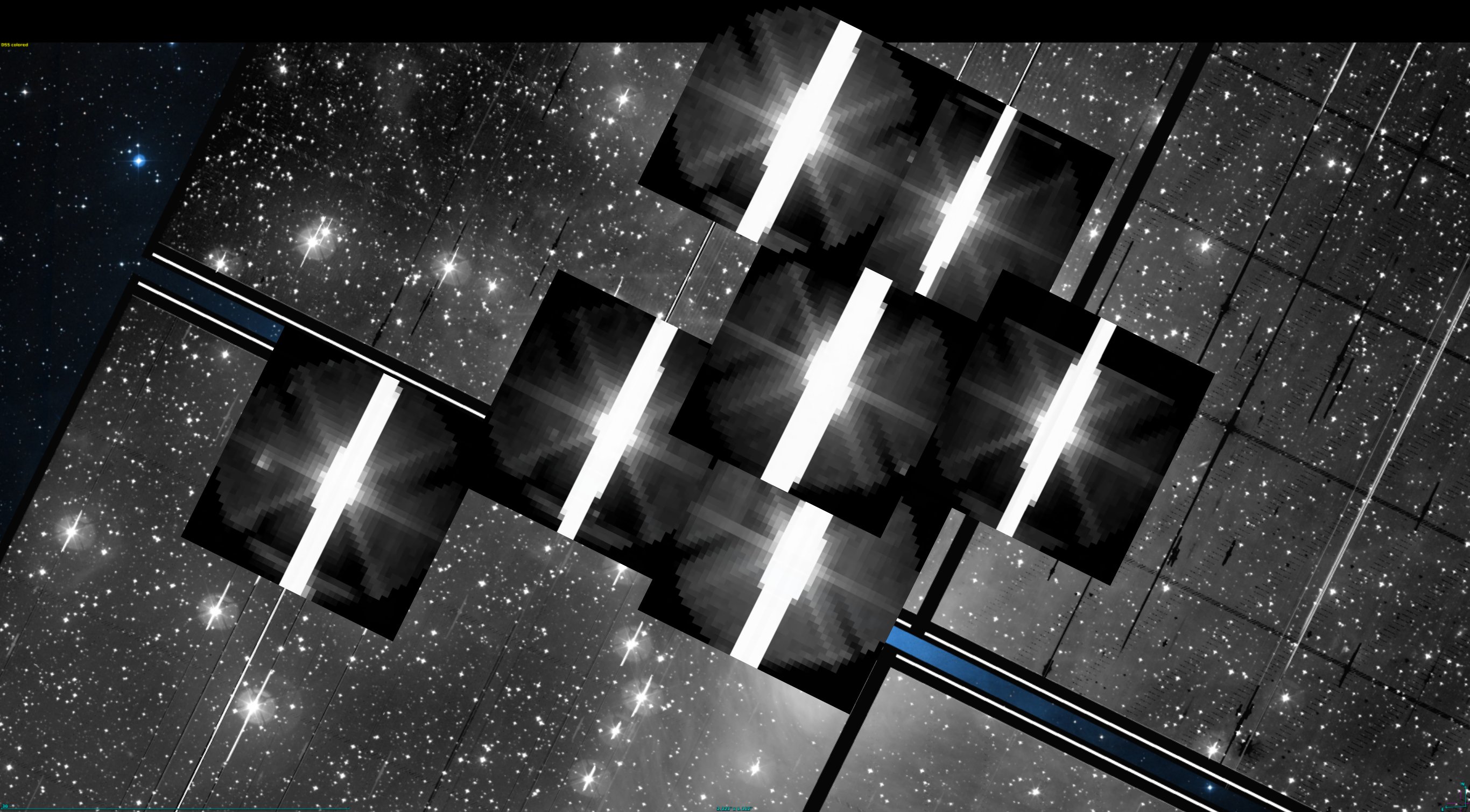


K2 Image of the Rho Ophiuchi cloud complex. This stellar nursery is one of the closest to our solar system and contains very young stars

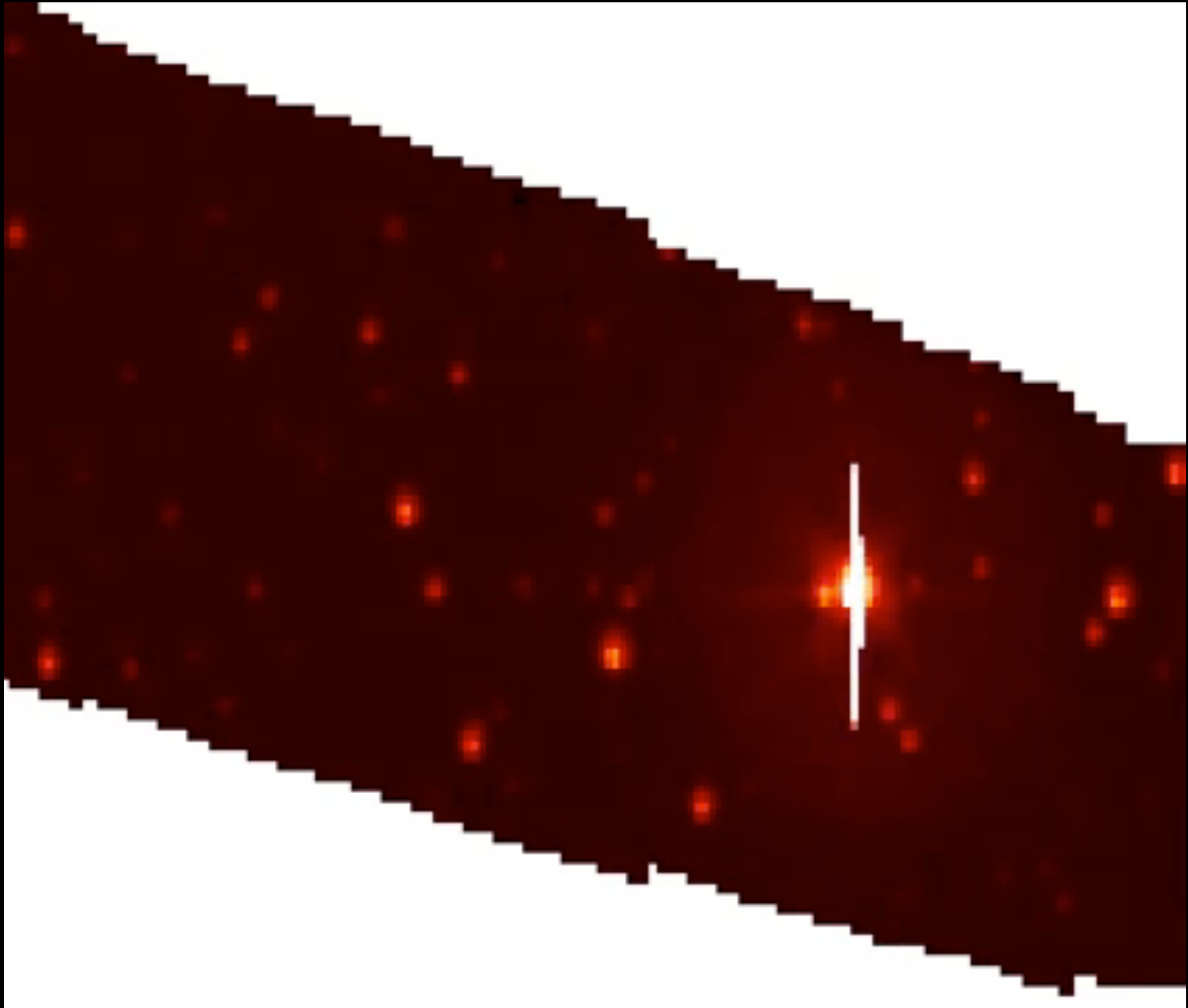
The Pleiades



Photometry of the Pleiades



Giant Planets in the Solar System



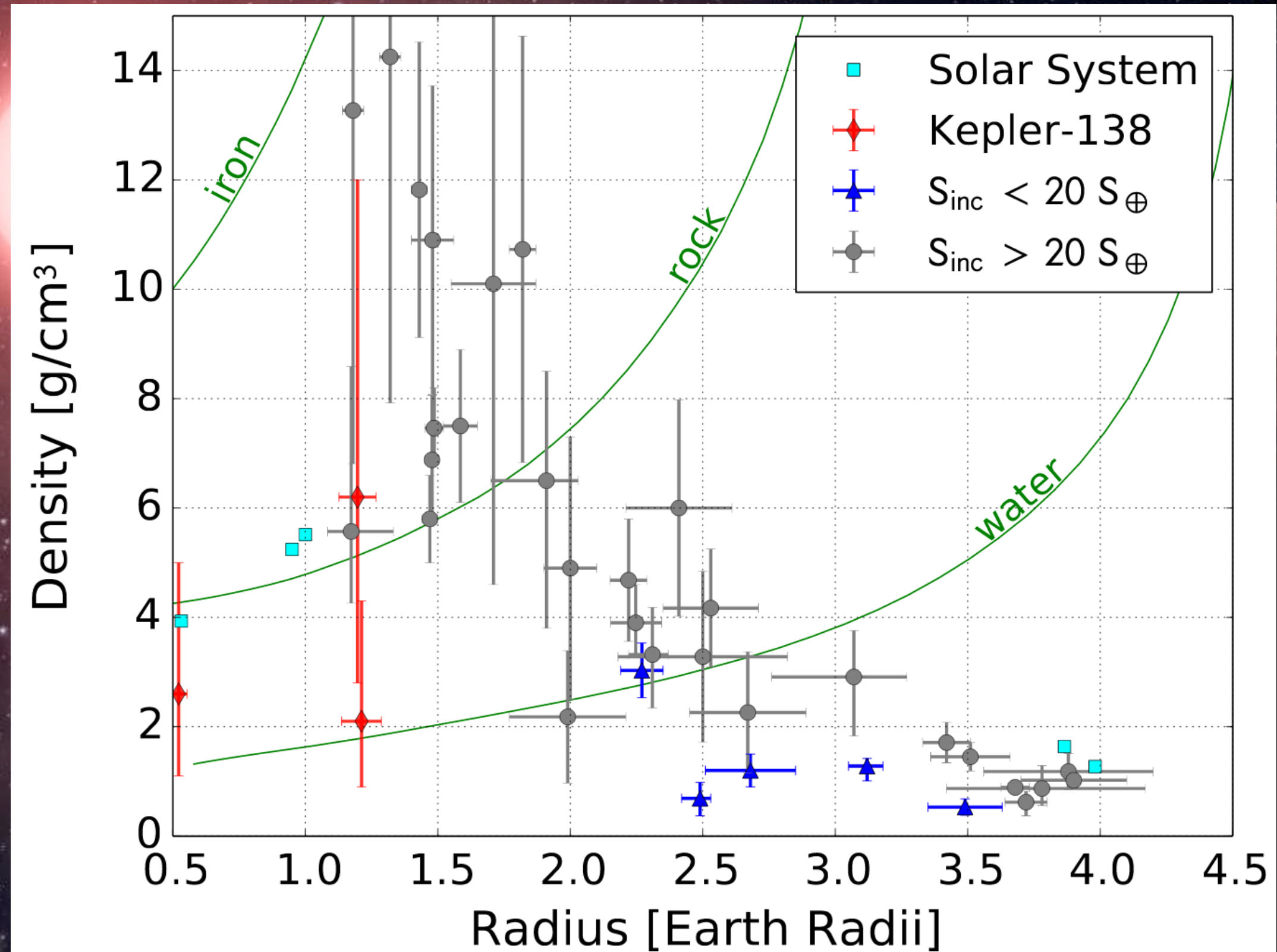
K2 is Still an Exoplanet Powerhouse

We have two main focus areas

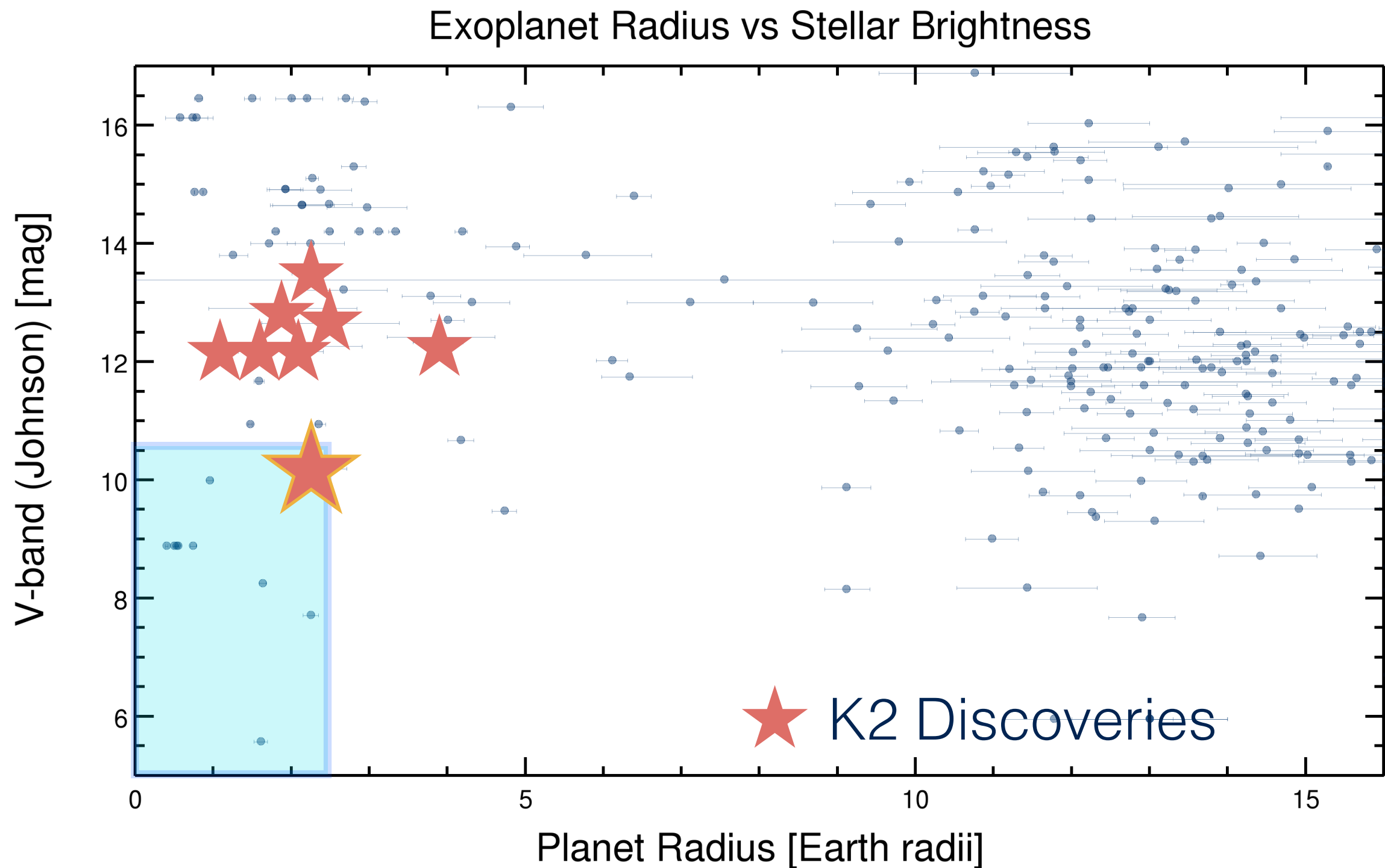
Finding exoplanets amenable to radial velocity follow-up

Detecting exoplanet orbiting nearby cool stars

Inferring Exoplanet Compositions

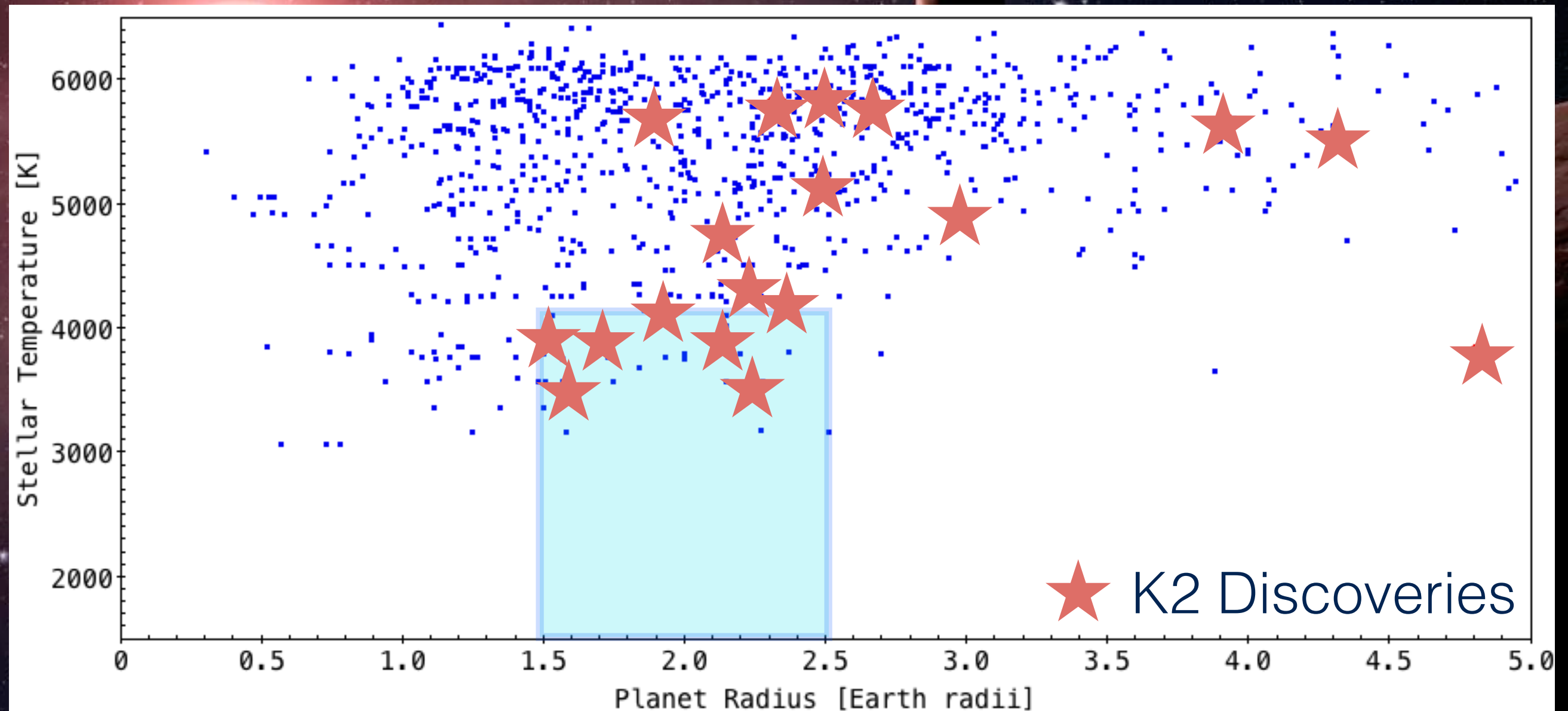


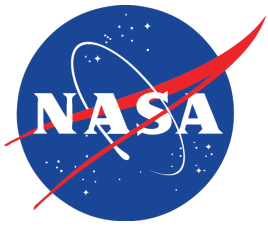
Inferring Exoplanet Compositions



Tue Aug 25 09:43:38 2015

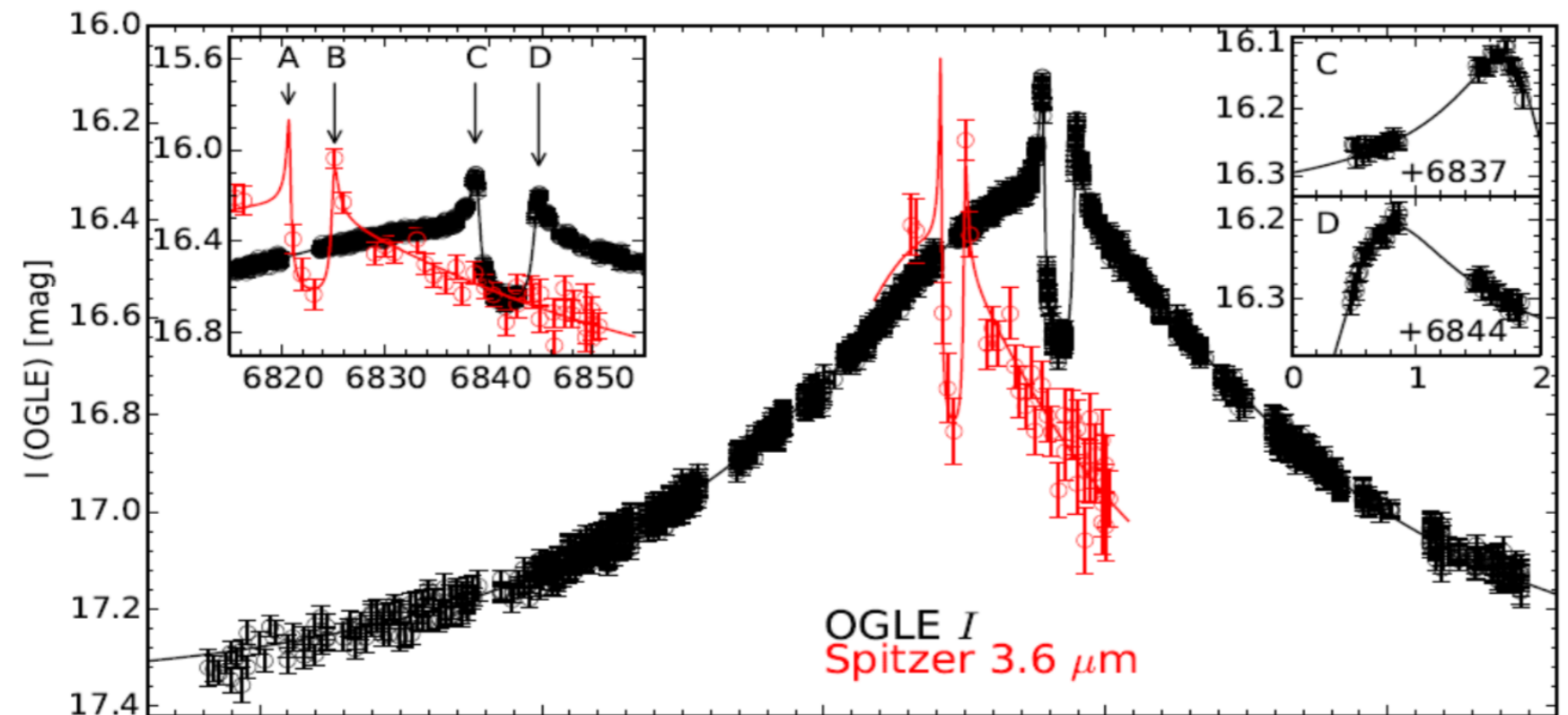
Super-earths orbiting cool stars

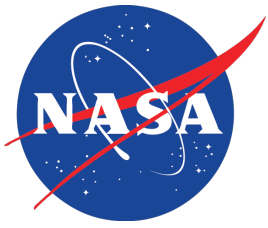




Campaign 9

Simultaneously
observe
Microlensing
events from K2
and Earth

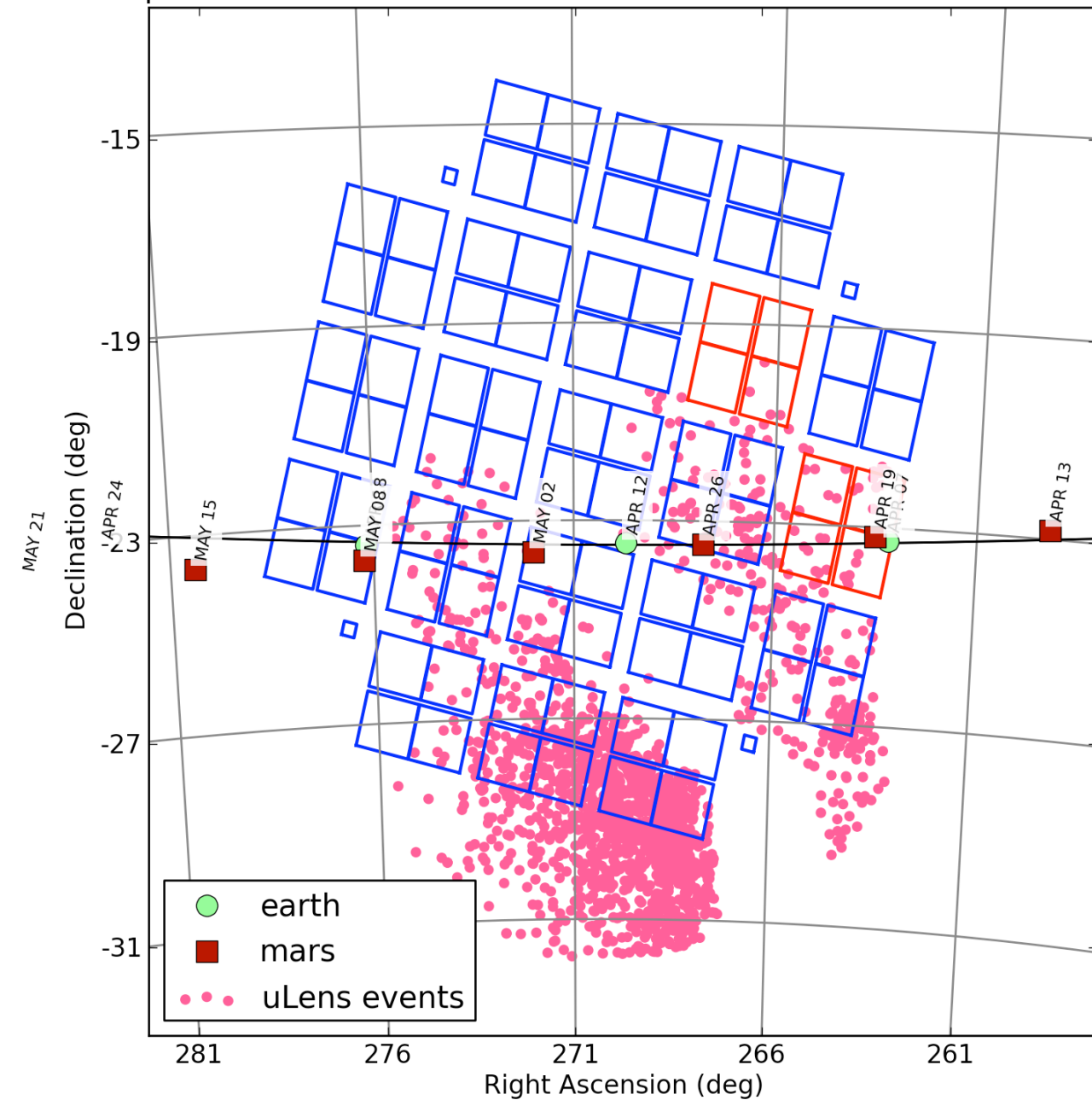




Observe the Bulge



Proposed Field 9: VV= 2016-05-07 Centre= 18 01 25.08 -21 46 47.3



Observations start April, 2016

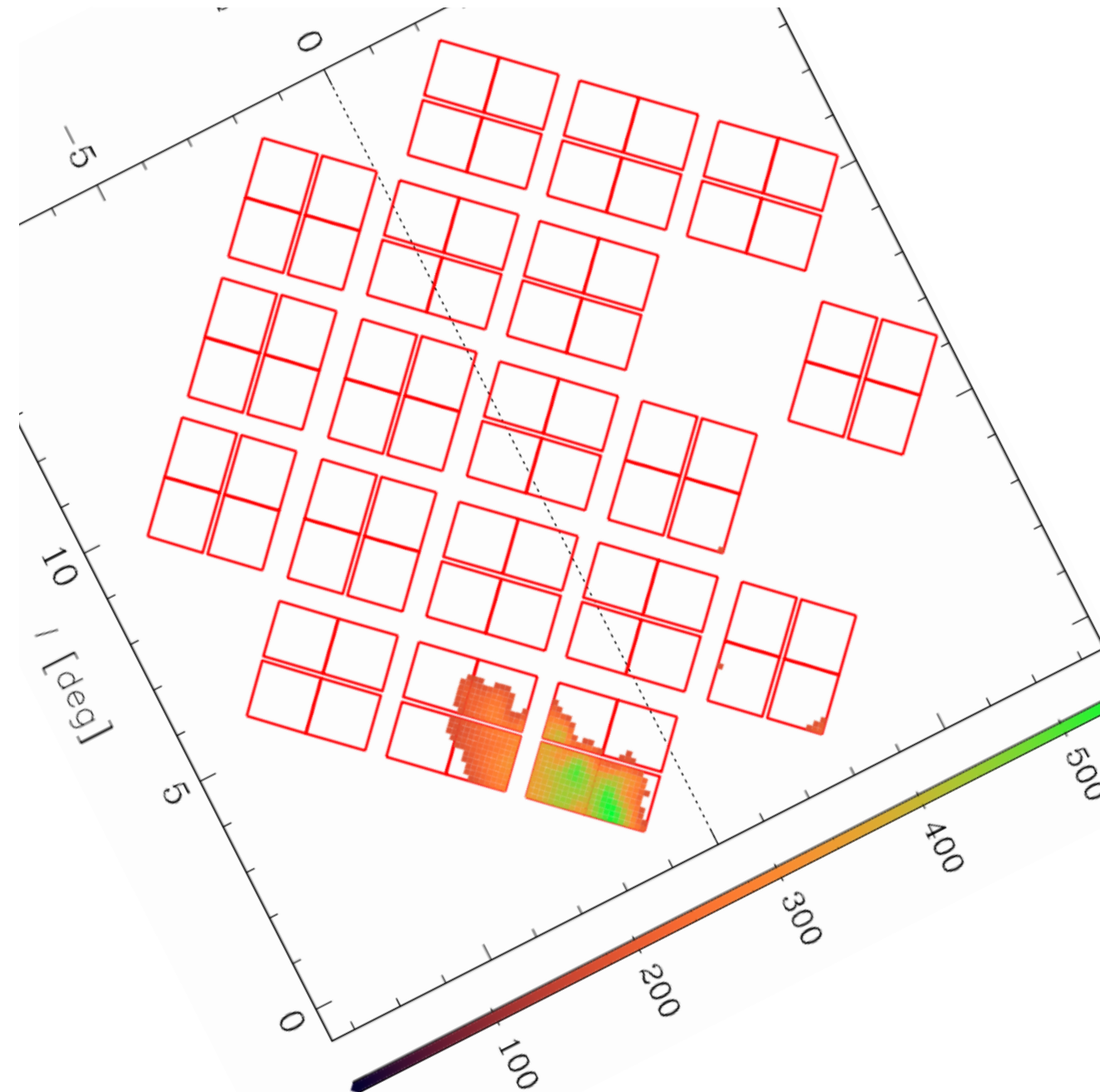
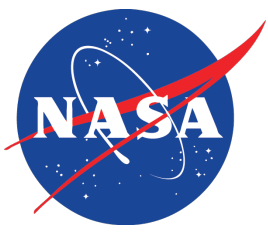


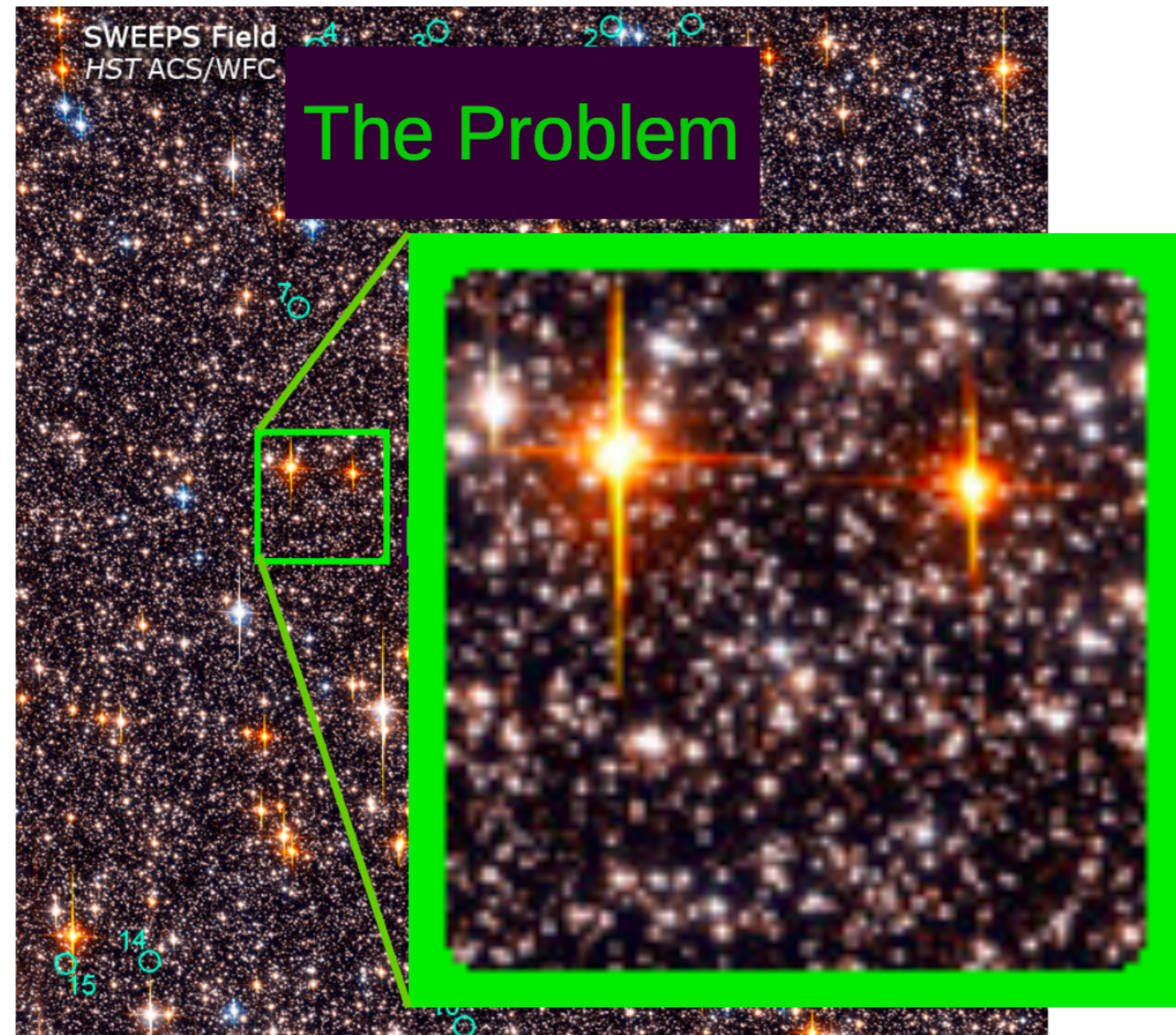
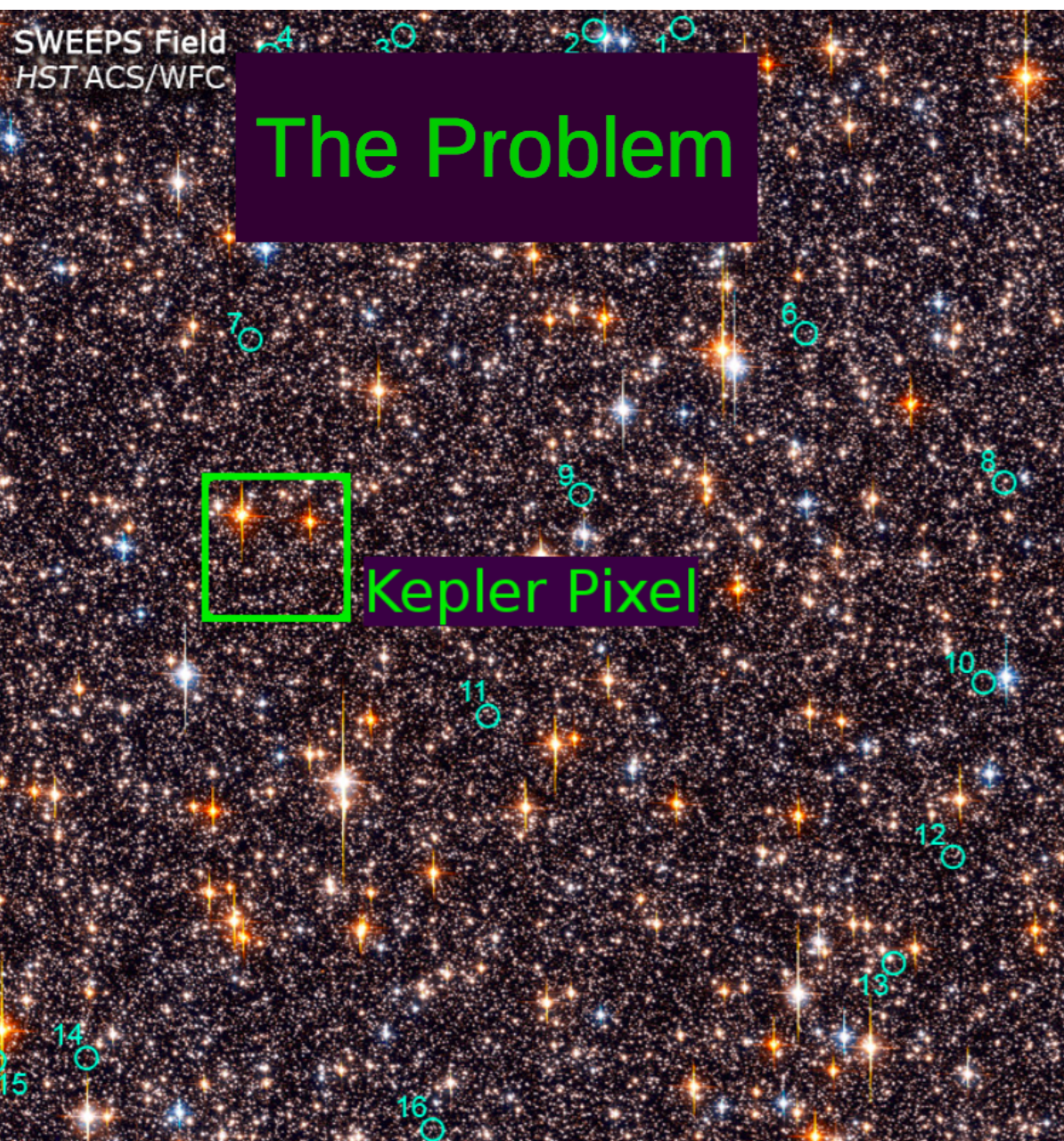
Image from Radek Poleski (OSU)

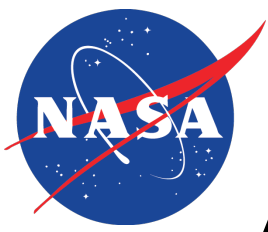


Photometry will be challenging

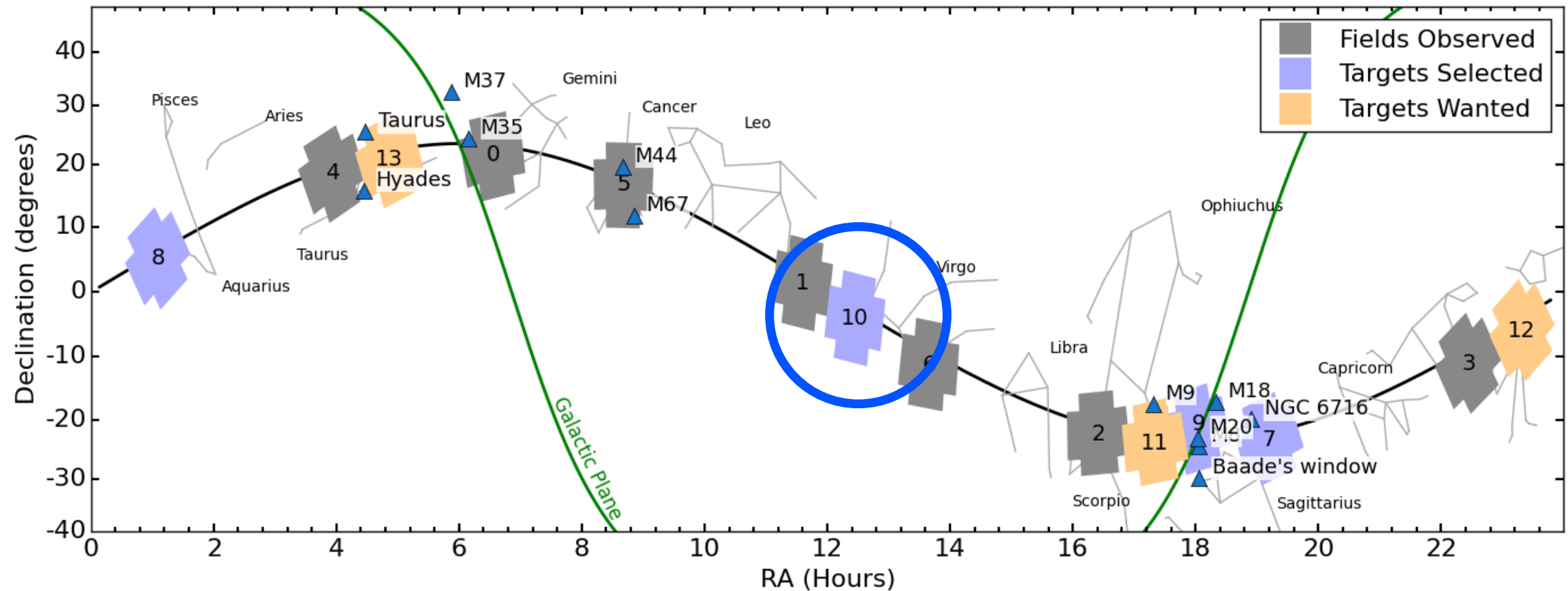


Images from Matthew Penny (OSU)





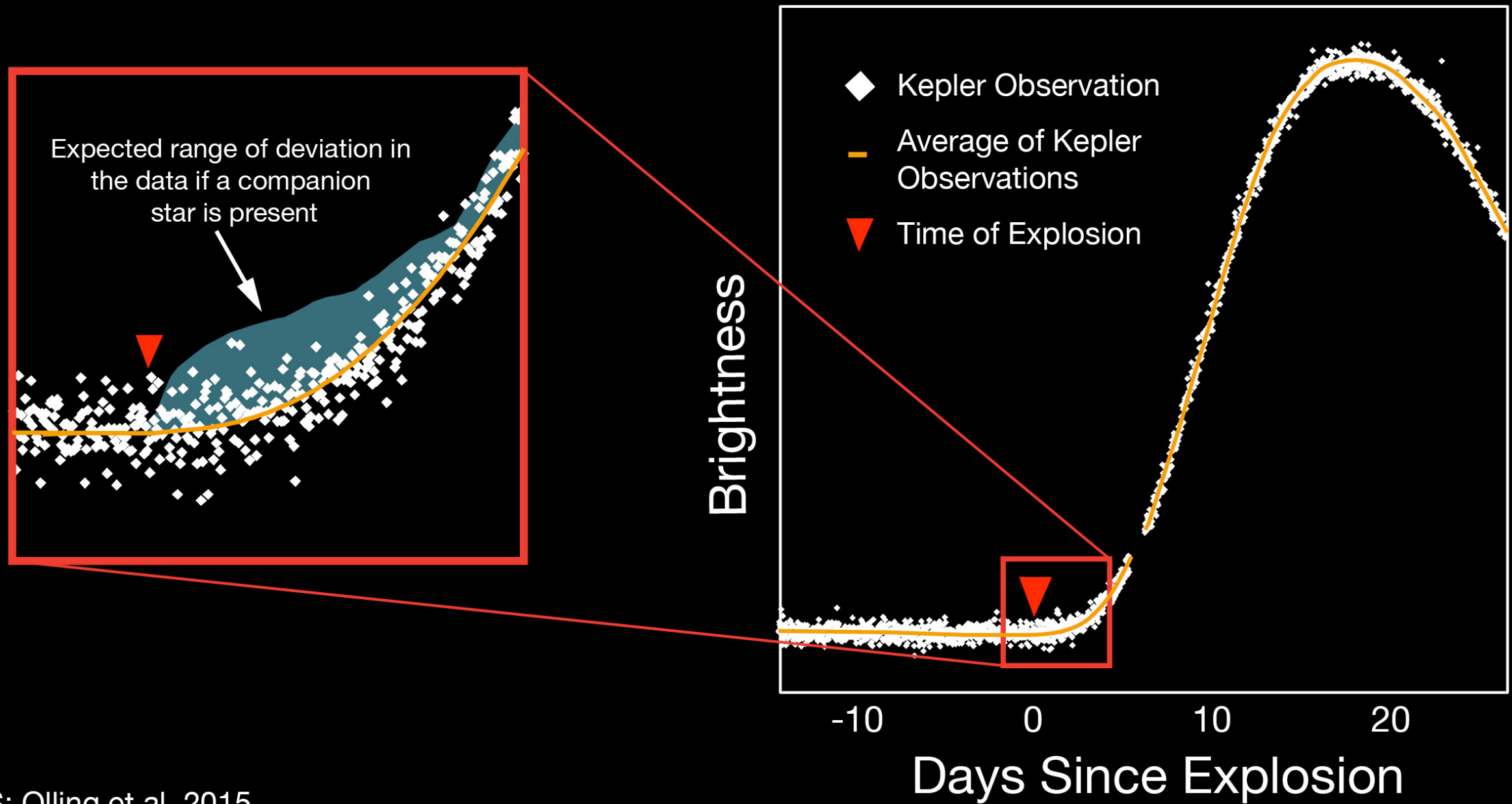
A Second Forward Facing Campaign

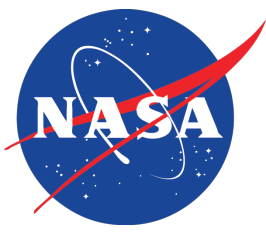


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- Potentially repeat Campaign 10 in the forward facing direction, focusing on extragalactic science

Kepler Observations of Supernova KSN 2011b





K2 SCI CON

FEATURING EXOPLANETS AND ASTROPHYSICS FROM K2, KEPLER, AND TESS



Santa Barbara, Nov 2-5, 2015

Registration now open!

**Early registration, hotel reservation & abstract submission deadline:
Sept 18**

- Science Topics
 - Asteroseismology
 - Exoplanets
 - Extragalactic Science
 - Microlensing
 - Solar System Science
 - Follow-up Activities
 - Future Missions and Long-Term Planning

Meeting will take place in
Santa Barbara, California

<http://lcogt.net/k2scicon/>